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Analyzing the Accreditation Venture of the Undergraduate Robotics Engineering Program

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Interactive Qualifying Project – Analyzing the Accreditation Venture of the Undergraduate Robotics Engineering Program

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Abstract

This study investigated how prepared the Worcester Polytechnic Institute (WPI) Robotics Engineering (RBE) program is to undergo the ABET accreditation process. Students, graduates, and professors associated with the RBE program and ABET accreditation were interviewed and surveyed. Data collected from surveying was used to determine areas in which the RBE program is succeeding as well as areas where the program could improve.

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1 Introduction

We are a group of four Worcester Polytechnic Institute (WPI) students who conducted a study for our Interactive Qualifying Project (IQP.) The focus of this study was the WPI Undergraduate Robotics Program. The goal of the program is to obtain ABET accreditation when it goes under review in the fall of 2010.

Our project was to create recommendations as to how to improve the RBE program, as well as write a portion of the self-study report that is submitted to ABET once an accreditation visit is requested. In order for the RBE program to pass the accreditation review, it must meet certain standards set up by the organization. There are many sections of these standards, but we focused on ABET's second, third, and fourth sets of criteria. We were best able to contribute to these sections because they pertain directly to the students-a group that we had relatively easy access to when looking for program feedback.

There are numerous advantages to getting the robotics program accredited. An accredited program looks much more appealing to employers because they can be sure that the students they are hiring are well-prepared for engineering positions. Students can also feel assured that they are learning everything they will need for a successful career in robotics. Not only will the students benefit from having an accredited program, but WPI will benefit as well. The University would most likely end up attracting more prospective students with its ability to offer a professionally accredited and recognized degree.

Background information on the topic of this study is provided in Section 2 of this paper. Since the Undergraduate Robotics Program at WPI is the main target for improvement, a description of the program and its missions has been included. ABET must approve of the program, and has criteria for the portion of the self study report that we wrote. Normally, the cognizant professional society associated with a major is the group who creates the criteria that ABET evaluates a school on. Due to the fact that robotics is so new, there is not yet a professional society in existence. Because of this, we have had to base our work off of the standard ABET criteria.

ABET accreditation is more than just a set of criteria, it is a process. This process has been researched and compiled into a simplified description as it pertains to our study. Further information is supplied through interviews with WPI professors who have firsthand experience with ABET accreditation.

The steps we took toward completing this study are described in the methodology under Section 3. The overall goal was to contribute to the RBE self-study report, so this section of our paper goes through what we did to make that happen. The parts that we were able to contribute to the most were Section 2: Program Educational Objectives, and Section 3: Program Outcomes. The methodology includes each task we completed and how it was applied to the study.

The results of all our work is documented in Section 4. A large portion of this section is dedicated to graphs created from data obtained while surveying WPI RBE students. A description of what each graph represents is provided, as well as analysis as to what the information means and can be used for when it comes to program improvement. In addition to the multiple graphs, two sections of the RBE self-study report were produced. The sections are included in full.

The analysis of our results, which can be found in Section 5, is somewhat broken up. Because there is a lot of information that goes along with each of our graphs, the analysis of each one has been placed in the results section with its corresponding graph for easy reference during the reading of the analysis.

What is included in this section is our analysis of the self-study sections we produced. It was important that these sections fulfill the ABET criteria, so our analysis describes how the parts we wrote are capable of satisfying an evaluator.

2   Literature Review

Extensive research was done before this project was started. The research provided us with crucial background information on our topic and allowed for the creation of a more effective, efficient, and well informed methodology. The areas of research included the Undergraduate Robotics Program at WPI and why its accreditation is desired, ABET's criteria and accreditation process, as well as interviews with various ABET-experienced WPI professors.

2.1   Undergraduate Robotics Program at WPI

Worcester Polytechnic Institute (WPI) approved the creation of a Robotics Engineering (RBE) undergraduate degree program in the fall of 2006.[1] The Robotics Resource Center (RRC) was formed to develop the program curriculum and oversee the introduction and establishment of the program. In the three years since, the Robotics Engineering program has grown at a substantial rate. Each year, more staff members have been hired and more courses offered in order to accommodate the growing number of students in the program. WPI awarded the first few Undergraduate Robotics Engineering degrees in the world in the spring of 2009.

The Robotics Engineering major was created to serve the apparent need for future engineers in the robotics industry to be proficient in more than just one type of engineering, such as Computer Engineering or Electrical Engineering. The staff at WPI saw this need, and decided that a program and curriculum should be created to produce such engineers. The disciplines they singled out as important for the development of a Robotics Engineering program were: "Computer Engineering, Computer Science, Electrical Engineering, Mechanical Engineering, and Software Engineering."[2]

The mission statement of the Robotics Engineering program at WPI states that the program "prepares undergraduates for work and advanced study in Robotics – the combination of sensing, computation and actuation in the real world."[3] The program describes the robotics industry as the common supply and demand model, where "the supply is driven by decreasing cost and increasing availability of sensors, computing devices, and actuators."[4] Demand is labeled as the needs of industries, and their desire to use robotics to advance their fields. The mission of the program is to "provide students with both the disciplinary fundamentals and interdisciplinary outlook needed for success in this dynamic and growing new professional field" of robotics.

The educational program objectives and educational outcomes of the Robotics Engineering undergraduate degree program at WPI, as stated in the undergraduate course catalog, are listed below.

RBE Program Educational Objectives[5]

The Robotics Engineering Program strives to educate men and women to:

- Have a basic understanding of the fundamentals of Computer Science, Electrical and Computer Engineering, Mechanical Engineering, and Systems Engineering.
- Apply these abstract concepts and practical skills to design and construct robots and robotic systems for diverse applications.
- Have the imagination to see how robotics can be used to improve society and the entrepreneurial background and spirit to make their ideas become reality.

- Demonstrate the ethical behavior and standards expected of responsible professionals functioning in a diverse society.

RBE Program Outcomes [6]

Graduating students will have:

- an ability to apply broad knowledge of mathematics, science, and engineering,
- an ability to design and conduct experiments, as well as to analyze and interpret data,
- an ability to design a robotic system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability,
- an ability to function on multi-disciplinary teams,
- an ability to identify, formulate, and solve engineering problems,
- an understanding of professional and ethical responsibility,
- an ability to communicate effectively,
- the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context,
- a recognition of the need for, and an ability to engage in life-long learning,
- a knowledge of contemporary issues, and
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

2.2 ABET Criteria

In order for an undergraduate engineering program to become ABET accredited, it needs to follow the guidelines of some well thought out criteria. "The quality standards programs must meet to be ABET-accredited are set by the ABET professions themselves. This is made possible by the collaborative efforts of many different professional and technical societies. These societies and their members work together through ABET to develop the standards, and they provide the professionals who evaluate the programs to make sure they meet those standards."[7] These criteria have been established to ensure that the program being evaluated is of a high quality, and doing everything necessary to prepare its students for a successful career.

ABET has laid out nine sets of criteria. They cover a broad range of educational topics and provide good checks to establish a well-rounded and continuously improving program. The criterions are as follows:

GENERAL CRITERIA FOR BACCALAUREATE LEVEL PROGRAMS

Criterion 1. Students

The program must evaluate student performance, advise students regarding curricular and career matters, and monitor students' progress to foster their success in achieving program outcomes, thereby enabling them as graduates to attain program objectives.

The program must have and enforce policies for the acceptance of transfer students and for the validation of courses taken for credit elsewhere. The program must also have and enforce procedures to assure that all students meet all program requirements.

Criterion 2. Program Educational Objectives

These objectives are designed to be goals three to five years out of college. Each program for which an institution seeks accreditation or reaccreditation must have in place:

(a) published educational objectives that are consistent with the mission of the institution and these criteria

(b) a process that periodically documents and demonstrates that the objectives are based on the needs of the program's various constituencies

(c) an assessment and evaluation process that periodically documents and demonstrates the degree to which these objectives are attained.

Criterion 3. Program Outcomes

These are goals that every student should have accomplished by graduation. Engineering programs must demonstrate that their students attain the following outcomes:

(a) an ability to apply knowledge of mathematics, science, and engineering

(b) an ability to design and conduct experiments, as well as to analyze and interpret data

(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability

(d) an ability to function on multidisciplinary teams

(e) an ability to identify, formulate, and solve engineering problems

(f) an understanding of professional and ethical responsibility

(g) an ability to communicate effectively

(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

(i) a recognition of the need for, and an ability to engage in life-long learning

(j) a knowledge of contemporary issues

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Program outcomes are outcomes (a) through (k) plus any additional outcomes that may be articulated by the program. Program outcomes must foster attainment of program educational objectives. There must be an assessment and evaluation process that periodically documents and demonstrates the degree to which the program outcomes are attained.

Criterion 4. Continuous Improvement

Each program must show evidence of actions to improve the program. These actions should be based on available information, such as results from Criteria 2 and 3 processes.

Criterion 5. Curriculum

The curriculum requirements specify subject areas appropriate to engineering but do not prescribe specific courses. The faculty must ensure that the program curriculum devotes adequate attention and time to each component, consistent with the outcomes and objectives of the program and institution. The professional component must include:

(a) one year of a combination of college level mathematics and basic sciences (some with experimental experience) appropriate to the discipline

(b) one and one-half years of engineering topics, consisting of engineering sciences and engineering design appropriate to the student's field of study. The engineering sciences have their roots in mathematics and basic sciences but carry knowledge further toward creative application. These studies provide a bridge between mathematics and basic sciences on the one hand and engineering practice on the other. Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often

iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs.

(c) a general education component that complements the technical content of the curriculum and is consistent with the program and institution objectives. Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints.[8]

Criterion 6. Faculty

The faculty must be of sufficient number and must have the competencies to cover all of the curricular areas of the program. There must be sufficient faculty to accommodate adequate levels of student-faculty interaction, student advising and counseling, university service activities, professional development, and interactions with industrial and professional practitioners, as well as employers of students.

The program faculty must have appropriate qualifications and must have and demonstrate sufficient authority to ensure the proper guidance of the program and to develop and implement processes for the evaluation, assessment, and continuing improvement of the program, its educational objectives and outcomes. The overall competence of the faculty may be judged by such factors as education, diversity of backgrounds, engineering experience, teaching effectiveness and experience, ability to communicate, enthusiasm for developing more effective programs, level of scholarship, participation in professional societies, and licensure as Professional Engineers.

Criterion 7. Facilities

Classrooms, laboratories, and associated equipment must be adequate to safely accomplish the program objectives and provide an atmosphere conducive to learning. Appropriate facilities must be available to foster faculty-student interaction and to create a climate that encourages professional development and professional activities. Programs must provide opportunities for students to learn the use of modern engineering tools. Computing and information infrastructures must be in place to support the scholarly activities of the students and faculty and the educational objectives of the program and institution.

Criterion 8. Support

Institutional support, financial resources, and constructive leadership must be adequate to assure the quality and continuity of the program. Resources must be sufficient to attract, retain, and provide for the continued professional development of a well-qualified faculty. Resources also must be sufficient to acquire, maintain, and operate facilities and equipment appropriate for the program. In addition, support personnel and institutional services must be adequate to meet program needs.[9]

Criterion 9. Program Criteria

Each program must satisfy applicable Program Criteria (if any). Program Criteria provide the specificity needed for interpretation of the baccalaureate level criteria as applicable to a given

discipline. Requirements stipulated in the Program Criteria are limited to the areas of curricular topics and faculty qualifications. If a program, by virtue of its title, becomes subject to two or more sets of Program Criteria, then that program must satisfy each set of Program Criteria; however, overlapping requirements need to be satisfied only once.

2.3   Our Focus

Most of our focus will be on evaluating how well WPI is meeting the standards of Criterion 2- Program Educational Objectives, Criterion 3- Program Outcomes, and Criterion 4- Continuous Improvement. The Institute has its Program Educational Objectives and Program Outcomes (titled Educational Outcomes) listed in its course catalogue, and also on its website dedicated to undergraduate robotics engineering:
http://www.wpi.edu/academics/Majors/RBE/academics.html.

ABET does not have specific objectives that a University can use as its own. What ABET lists are standards that a program's objectives must meet. In contrast to ABET's Educational Objectives, the suggested ABET Program Outcomes can be used word for word. The Robotics Engineering Program chose to use the ABET Program Outcomes, with some minor alterations. The differences are important to be aware of because ABET must approve of a program's Educational Outcomes. Therefore, the more similar a set of outcomes is to ABET's, the more likely they are to be approved.

Listed below are the WPI Robotics Engineering Educational (same as Program) Outcomes. Words that WPI added to the ABET Outcomes are distinguished through italicizing and underlining.

Educational Outcomes

Graduating students will have:

- an ability to apply _broad_ knowledge of mathematics, science, and engineering,
- an ability to design and conduct experiments, as well as to analyze and interpret data,
- an ability to design a robotic system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability,
- an ability to function on multi-disciplinary teams,
- an ability to identify, formulate, and solve engineering problems,
- an understanding of professional and ethical responsibility,
- an ability to communicate effectively,
- the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context,
- a recognition of the need for, and an ability to engage in life-long learning,
- a knowledge of contemporary issues, and
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

This shows that WPI is well aware of what goals its students must reach to be in compliance with ABET standards.

When it comes to Criterion 4, the RBE Program's continuous improvement plan does not appear to be currently documented. The program is so new that a continuous improvement plan has not been fully developed, rather observations are still being made to target the areas of weakness that need a plan for improvement.

2.4 Why is accreditation important to the RBE major?

According to the ABET website, "accreditation is a non-governmental, peer-review process that assures the quality of the postsecondary education students receive." This gives educational institutions and programs an option for determining whether they meet certain standards. Unlike in other countries, in the United States this option is purely voluntary. Accreditation is not a method for ranking institutions; it is only a method for determining how well an institution meets certain standards and requirements.

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There are two types of accreditation: Institutional accreditation and Specialized accreditation. Institutional accreditation is for accreditation of an entire institution as opposed to specialized accreditation which is for accrediting individual programs at an institution. The type of accreditation the Robotics Engineering (RBE) program at WPI is seeking is specialized accreditation from ABET, Inc.

ABET claims that "ABET accreditation is assurance that a college or university program meets the quality standards established by the profession for which it prepares its students." This means that for the RBE program to become accredited, it must meet quality standards set by the Robotics profession.[10]

The ABET website states that ABET accreditation is important because: "accreditation helps students and their parents choose quality college programs, accreditation enables employers to recruit graduates they know are well-prepared, accreditation is used by registration, licensure, and certification boards to screen applicants, and accreditation gives colleges and universities a structured mechanism to assess, evaluate, and improve the quality of their programs." This means that accreditation of the RBE program has the potential to help WPI attract parents and students, especially when other institutions develop their own robotics engineering programs. Accreditation of the RBE program would help students gain more and better employment positions, which would in turn help WPI in its rankings and in its ability to attract students and parents. Accreditation would help graduates of the RBE program become licensed more easily. Seeking accreditation would give WPI a method for determining whether the RBE program is teaching students what they need to learn, and what can be done to improve the program.

According to the ABET website, "employers, graduate schools, and licensure, certification, and registration boards, graduation from an accredited program signifies adequate preparation for entry into the profession." In fact, many of these groups require graduation from an accredited program as a minimum qualification. Here are some examples

NICET Technologist Certification requires a bachelor's degree from an ABET-accredited engineering technology program.

The United States Patent and Trademark Office requires applicants in computing to have graduated from an ABET-accredited computing program before they are eligible to sit for the Examination for Registration to Practice in Patent Cases.

Many state boards of professional licensure in engineering and surveying require applicants to have graduated from an ABET-accredited program. In states where non-ABET graduates are permitted to be licensed; an additional four to eight years of work experience may be required.

These certification bodies require additional experience and/or credentials evaluation for applicants who have graduated from non-ABET-accredited programs:

- American Board of Industrial Hygiene
- Board of Certified Safety Professionals
- Construction Manager Certification Institute
- Council on Certification of Health, Environmental, and Safety Technologists
- Association for the Advancement of Cost Engineering"[11]

2.5   Process of ABET Accreditation

The Accreditation Board for Engineering and Technology (ABET) was established in 1932 in order to create a joint program that would better the field of engineering as a profession. ABET is responsible for establishing standards, procedures, and an environment that will encourage the highest quality for engineering, engineering technology, and engineering-related education through accreditation so that each graduate possesses the skills necessary for lifelong learning and productive contribution to society, the economy, employers, and the profession. The ideals are to assure high quality subjects through means of continuous improvement, improve the understanding of the accreditation process, cooperate with public and private entities to identify and assist on educational improvements, and sponsor appropriate conferences and studies that will benefit the entire spectrum of engineering. ABET is a coalition of twenty seven engineering professional technical societies that represent more than 1.8 million engineers. [12]

These are the ideals that ABET has followed since it was established; however, over the past decade its procedure for completing this task has changed. The most up to date process that the ABET analysis follows is:

- *Mission* - Assessment planning begins with the institutional mission statement. The institutional mission statement describes the communities that are served, institutional purposes and other characteristics that define the institution.
- *Educational Objectives* - statements that describe the expected accomplishments of graduates during the first few years after graduation—usually 3-5 years. These objectives should be consistent with the mission of the program and the institution. Educational objectives need to be assessed and evaluated periodically. This is generally done through alumni, employer, recruiter, and/or advisory board assessment. The objectives should be evaluated on a systematic basis to determine their continued relevance to the needs of constituents. This evaluation is done every three to five years, which is how it will occur with the robotics engineering major.
- *Learning Outcomes* - statements that describe what students are expected to know and/or be able to do by the time of graduation. If students have achieved these outcomes, it is anticipated that they will be able to achieve the educational objectives after graduation.
- *Performance criteria* - statements which define the learning outcomes. These criteria are high level indicators that represent the knowledge, skills, attitudes or behavior students should be able to demonstrate by the time of graduation that indicate competence related to the outcome.
- *Educational Practices/Strategies* - Understanding the comparisons between how students are getting taught vs. what the students are learning promotes efficient and effective assessment practices. This can be accomplished by mapping educational strategies (which could include co-curricular activities) to learning outcomes.
- *Assessment, Collection and Analysis of Data* - Strategies for data collection and analysis need to be developed that are consistent with the assessment question and the resources available.
- *Evaluation* - the process that is used to determine the meaning of the assessment results. This includes the implications of assessment results related to program effectiveness and recommendations for improvement.

This process stresses the idea that the criteria needs to fulfill the ABET needs, otherwise, it will not sufficiently build the minds of any aspiring engineers.[13]

As we began to analyze the RBE major through this process, we needed to be able to understand the terminology, according to Professor Demetry, so that we did not misinterpret any of the data that we collected throughout our interviewing process. The terminologies that seem to be most important are the following:

- *Objectives* – statements that describe the expected accomplishments of graduates during the first few years after graduation
- *Outcomes* – statements that describe what students are expected to know and be able to do by the time of graduation
- *Performance* criteria – specific, measurable statements that identify the performance required to meet the outcome, which can be confirmed through evidence
- Assessment – processes that collect, identify, analyze and report data that can be used to evaluate achievement
- *Evaluation* – process of reviewing the results data collection and analysis and making a determination of the value of findings as well as the actions that should be taken.

Throughout our research we have encountered these terminologies. We believe that a full understanding of these terms is necessary before they can be properly used in an assessment process.[14]

2.6   Interviews
Within the following section is documentation of the interviews conducted with various WPI
professors who have knowledge of the ABET system.

2.6.1   Interview with Professor Demetry
We met with Professor Chrysanthe Demetry in order to get a better understanding of what the
ABET accreditation process is about and where we should start with our project. The following
details what we learned from her.

To get a better idea of what the ABET accreditation process entails, she advised us to meet with
specific people in the departments at WPI that have already been accredited, such as the
Biomedical Engineering, Civil Engineering, Electrical and Computer Engineering, Computer
Science, and Chemical Engineering departments. She explained that it would be especially
beneficial to meet with people from the Aerospace Engineering and Environmental Engineering
departments because they just completed the ABET accreditation process. She said that there is
supposed to be a person in each department who is in charge of gaining or maintaining
accreditation for their department. This person and the department head are the best people to
talk to about the accreditation process.

The following is a table of accredited departments (according to the ABET website) and people
in each department who we considered meeting with:

Table 1

Department	Accredited?	Department Head
Biomedical Engineering	Yes.	Ki Chon
Chemical Engineering	Yes.	David DiBiasio
Civil and Environmental Engineering	Yes.	Tahar El-Korchi
Electrical and Computer Engineering	Yes.	Fred J. Looft III
Industrial Engineering	Yes.	Amy Zeng
Mechanical Engineering	Yes.	Grétar Tryggvason
Computer Science	Yes, but under computing.	Michael A. Gennert
Aerospace Engineering	Not according to the ABET website.	Nikolaos A. Gatsonis
Environmental Engineering	Yes	Jeanine Plummer

Professor Demetry wanted us to note that WPI's Computer Science Program is ABET
accredited, it is accredited by the Computing Accreditation Commission rather than the
Engineering Accreditation Commission. Also, WPI's Aerospace Engineering program is
accredited, but it has not shown up as such on the ABET website yet; however, it will be by the
summer of 2010.

She explained to us that the department heads should be able to provide information about who
in the department has the responsibility of dealing with ABET accreditation. Also, that whoever

is in charge of accreditation should have plenty of reports prepared for the ABET visits that can be used for reference and comparison.

She suggested that Professor DiBiasio was very important to talk to because not only was he in charge of getting the Chemical Engineering major accredited, but he happens to be one of the people who goes to other schools and evaluates them for ABET accreditation. He would be able to help with looking at the accreditation process from both sides. That brought up another important point: How exactly is a program evaluated? What is involved in the process of assessing program outcomes?

Professor Demetry lent us a short text on exactly this written by Gloria Rogers.[15] It has a number of important sections to it:

1. *Identify Goals*- a statement describing the broad outcome desired. A goal should be far reaching and describe the best situation that could possibly be hoped for

2. *Identify Objectives*- derived from the goal that define the circumstances by which it will be known if the desired change has occurred. Objectives are precise in stating expected change, how the change should occur, the expected level of change and over what time period the change is expected.

3. *Develop Performance Criteria*- specific statement identifying performance required to meet the objectives. The performance must be confirmable through evidence and may have multiple criteria. Indicators of performance must be sought in order to directly assess the performance.

4. *Determine Practices*- classroom and/or institutional practices designed to achieve a specific performance.

5. *Specify Assessment Methods*- Processes used to collect evidence of outcome.

6. *Conduct Assessments*- determine specific methods to obtain the evidence.

7. *Determine Feedback Channels*- provides information in a timely fashion to facilitate continuous improvement of practices, provide information for decision making, and provide basis for evaluation.

8. *Evaluate*- in order to evaluate the analysis, a decision must be made concerning how many performance criteria must be met in order to say that the objective has been achieved.

Professor Demetry suggested that we also needed to look into the American Society for Engineering Education and the *Journal for Engineering Education*. She suggested these to help us better understand ABET outcomes and assessment.

Professor Demetry stressed how important it would be for us to meet with those who have already gone through the ABET accreditation process and how important it would be for us to determine exactly how programs get evaluated for accreditation. Our next step was to set up meetings with many of the department heads and to read through the piece by Gloria Rogers.

2.6.2   Interview with Professor Looft

Our group wanted to expand our involvement outside the 3a-3k criteria. Therefore, we decided to meet with Professor Looft, the head of the Electrical and Computer Engineering (ECE) department, to see what else we could assist with. The ECE department has recently gone through the ABET accreditation process and will also assist with the ABET accreditation of the RBE major. During our interview, we discussed various topics regarding the process that he recently went through, the difficulties that a few majors have had during their accreditation process, and the mapping of the 3a-k criteria to course objectives specific to the major.

Professor Looft sent us the ECE self-study, which compiled a summary of the students, program educational outcomes and objectives, improvement and curriculum. Examining the program outcomes and objectives in this study aided in the design of new ones for the RBE major. Also helpful were the program outcomes and objectives for the mechanical engineering and computer engineering majors. They are listed in the methodology.

Though the ABET accreditation process is based largely on the curriculum and other major factors, there is one that many people seem to overlook. The evaluator has a huge impact on the smoothness of the accreditation process that will occur. There was one specific example that occurred at WPI where the evaluator made a large difference to a major that was established during the creation of WPI. The mechanical engineering major experienced a difficult evaluator who told them that their 3a-k criteria were not sufficient according to the new ABET criteria. The mechanical engineering program was forced to reshape its criteria and map them back to the ABET 3a-k criteria. This problem may occur for the RBE major because the evaluators that ABET will send will all be most familiar with one specific major, that being ME, ECE or CS. This will create bias because they will believe that the RBE major does not go in depth enough in the three majors that it encompasses. In order for the RBE major to eliminate this bias, their curriculum must be comprised of the essential courses that are needed for a robotics major rather than the essential courses that are needed for the three individual majors.

2.6.3   Interview with Professor Dibiasio

We met with Professor David DiBiasio, head of WPI's chemical engineering department, in early October. Dr. DiBiasio's focus is in educational research. This involves engineering education, including international education, teaching and learning, and assessment. He has served as assessment coordinator for the Interdisciplinary and Global Studies Division and is Director of the Washington, D.C. project center. He has also served as the Chair of the Chemical Engineering Division of the American Society for Engineering Education (ASEE). He is an ABET evaluator and currently serves on the American Institute of Chemical Engineers' (AIChE) Education and Accreditation Committee.

Professor DiBiasio's experience with ABET is what we were looking to learn about in our interview. Because he has been through the accreditation process multiple times, his input as to what we should focus on when working with the robotics program was very valuable. We informed him that we were specifically analyzing the ABET 3a-k criteria. He expressed concern about this because the ABET criteria for each major is created and determined by its own professional society. Since robotics is so new, it does not yet have a professional group to make any criteria.

We were initially very stressed about this new information. We thought that there would be no point doing all of our research and mapping criteria if it did not truly exist in the first place; however, Professor DiBiasio suggested that we meet with Provost Orr, who was able to expand on this subject and change our outlook on the subject.

2.6.4   Interview with Professor Orr

We met with Provost John Orr in early November. Provost Orr "is a member of the ABET Engineering Accreditation Commission," and has served as multiple positions in accreditation visits before. Because he knows what the mindset of an ABET evaluator is like, we asked him to explain what he thought might be some issues that could come up when the robotics program goes through its evaluation.

He informed us that since robotics does not have its own set of program criteria, ABET's general criteria would be applied to our program. This was very good news, seeing as how we had previously expected to not be able to do any analysis until a professional society for robotics was formed and had created program criteria.

Provost Orr felt that we would need to explain to our evaluator that robotics is comprised of three different majors. He or she is going to see the words electrical, or mechanical, or computer science and most likely be surprised when the depth a robotics major must achieve in each of those subjects is lower than what a major in each of those subjects might be required to achieve. It is very difficult to combine three majors into one, and the evaluator needs to understand that robotics does not go as in depth for each category as would that category alone as a single major.

2.6.5   Interview with Professor El-Korchi

We met with Professor Tahar El-Korchi, Head of WPI's Civil & Environmental Engineering (CEE) Department, on November 12, 2009. Dr. El-Korchi was heavily involved in the accreditation of the Civil Engineering program.

Dr. El-Korchi explained to us that Civil Engineering and Environmental Engineering at WPI are two entirely separate majors that are both part of the CEE Department. As a Civil Engineering Major, a student can study Civil Engineering by itself, or he/she can be a Civil Engineering Major with a concentration in Environmental Engineering. An Environmental Engineering Major, however, cannot do a concentration in Civil Engineering.

We had hoped to find that the two majors had been accredited as one single program, Civil & Environmental Engineering, as the department title suggests and as many other schools in the United States choose to do. Our hope was to find another program like RBE which was a combination of multiple other programs in order to learn the pitfalls and other important information associated with accrediting a joint program. Unfortunately, Civil Engineering and Environmental Engineering are accredited as two separate programs.

Civil Engineering has been accredited and reaccredited many times now, and encounters very few issues with getting reaccredited. Environmental Engineering, however, is a new program at WPI, and became ABET accredited for the first time recently. It became clear that meeting with the Director of the Environmental Engineering Program would be very beneficial.

2.6.6   Interview with Professor Plummer

We met with Associate Professor Jeanine Plummer, Director of WPI's Environmental Engineering (EVE) Program, on November 12, 2009. Dr. Plummer wrote a large portion of the EVE Self-Study given to ABET as part of the process of the EVE Program becoming ABET Accredited. WPI's EVE Program received its initial accreditation in 2006 under the guidance of Dr. Plummer. It received the full, six-year accreditation, which is the longest length of accreditation that ABET offers. This was despite the fact that, according to Dr. Plummer, many evaluators believe that a program should not receive more than the two-year accreditation offered by ABET the first time they attempt accreditation because the programs may not have sufficient proof that they are working effectively.

Dr. Plummer showed us several sections of the Self-Study that was given to ABET. She showed and explained to us how she was able to map the outcomes and objectives of the EVE Program to ABET's 3a-k criteria using a table, and how she used many other tools throughout the document to prove that the EVE Program is satisfying all requirements put forth by ABET. She explained to us how after reviewing the program, the evaluator sent by ABET had only one major complaint with the program: its lack of funding, professors, and students. A lack of appropriate funding, professors, and students in the department made the evaluator concerned that the department would not be able to be sustained. At the time of evaluation, all of the professors who were teaching the EVE classes were being "borrowed" from other departments; none of these professors were part of the EVE department. This was only because EVE was such a new program and had no money at the time to pay for its own professors. ABET looks for a "vibrant" program, and the more students a program graduates per year, the more vibrant it is considered. The EVE program has graduated only one student to date. It had trouble convincing the evaluator that it was a vibrant program.

Dr. Plummer brought up several issues that the RBE program may run into when it gets evaluated: It may not have enough funding; it may not have enough of its own professors; and it may not be graduating enough students per year. All of these issues may be able to be overlooked by the evaluator under the assumption that the program is too new to have established enough funding, professors, and students; however, they may not be able to be overlooked, and thus, these issues may need to be fixed.

2.6.7   Interview with Professor Gennert

On November 18th, 2009 we met with Professor Gennert, head of the Computer Science (CS) department. He was able to enlighten us on a bevy of topics, ranging from the ABET evaluation that the CS department went through to the problems that he believes may cause some concern for the RBE major.

Professor Gennert described his evaluator as very persnickety because the criteria that the evaluator had problems with were criteria that had not been changed before. The new standards caused the CS major to receive an intermediate report (IR), which means that the CS department needs to fix their problems and send in a report within the next two years. The evaluation saw two concerns (potential for something to change such that a criterion may no longer be satisfied) and one weakness (lacking compliance to a criterion at time of evaluation such that action must be taken to strengthen compliance in that area.) The two concerns consisted of laboratory experience in the science courses and Criterion 9. The ABET evaluator believed that the students were not getting enough laboratory experience during their science courses and the program

criteria were not up to the ABET standards. Though these seem like minor problems when looking at the big picture, they still can cause a program to not achieve the full six-year accreditation.

The problems that Professor Gennert believes need to be addressed for the ABET evaluation are the science and math requirement and the engineering science and design requirement. For the math and science requirement, ABET criteria state that a student needs to take a full year's worth (12/3 units) of math, but the RBE major only requires 11/3 units. WPI has argued that one year of WPI work is defined as only 11/3 units because in order to graduate we need 44/3 units of work completed, which is 11/3 units per year. For the engineering science and design requirement, ABET requires that a student needs to take a year and a half worth of these courses; however, one of the courses under these requirements is Social Implications of Technology which may be viewed as a course that should not fulfill this requirement.

2.6.8 Harvey Mudd College of Engineering

We decided that it would be beneficial to get in contact with a college or university who has an engineering program accredited under the general engineering criteria. We chose the Harvey Mudd engineering program primarily because we had a contact at the school. This person was able to get us contact information for staff and faculty in the program that know about the accreditation process that their engineering program went through. Unfortunately, we never heard from these contacts, and were not able to gain any useful information about Harvey Mudd's ABET Accreditation process.

2.7 Conclusion

The background information from this section was an invaluable resource for completing our study. It was referenced several times during the creation of our methodology and the production of our surveys. The interviews with the professors were helpful in putting us on the right track toward understanding the ABET process and finishing this project successfully.

3   Methodology

The many steps involved in surveying students and drafting the self-study sections are described below.

3.1   RBE Self Study

3.1.1   Section 2

We created a new set of educational objectives for the RBE major, which can be mapped back to the ABET 3a-k criteria. This was done by taking the ABET approved educational objectives of the three majors that the RBE major encompasses (ME, CS and ECE), and combining them to produce a single set that well represents robotics engineering. The thinking behind this strategy was that robotics is a combination of three majors, and those three majors have already been accredited; therefore, a combination of their objectives should result in an acceptable set of custom objectives.

These objectives are listed in Section 2 of the Results section.

We were able to develop these objectives by analyzing the objectives of the three encompassed majors. The program objectives of the Mechanical Engineering major are:

1. A graduate should be able to apply the fundamental principles of mathematics, science, and engineering to solve structured problems in mechanical engineering.
2. A graduate should be able to combine fundamental knowledge of engineering principles and modern techniques to solve realistic, unstructured problems that arise in mechanical engineering.
3. A graduate should demonstrate the ability to design and develop useful products, processes, or systems that benefit society.
4. A graduate should develop interpersonal skills, ethical behavior, a professional attitude and a respect for others to function effectively in a team environment.
5. A graduate should demonstrate communications skills, write, oral, electronic and graphical, so that they can perform engineering functions effectively.

The program objectives of the Electrical and Computer Engineering major are:

1. An education which is strong both in the fundamentals and in state-of-the-art knowledge,
2. Preparation for immediate professional practice as well as graduate study and lifelong learning,
3. Broad preparation for their professional and personal lives, providing the basis for effective professional and civic leadership and informed citizenship,
4. Strength in all forms of technical and nontechnical communication,
5. The ability for effective teamwork,
6. An understanding of the broad social and ethical implications of their work.

The program objectives of the Computer Science major are:

1. Are prepared technically for computer science and software engineering practice.
2. Understand the basic principles of computer science and software engineering.
3. Understand appropriate mathematical concepts and are able to apply them to computational problems.
4. Have knowledge of computer hardware and architecture.
5. Understand and follow software engineering processes.
6. Are prepared to design and implement software systems.
7. Are prepared to analyze and evaluate software systems.
8. Understand fundamental scientific principles and the scientific method.
9. Can function effectively in diverse teams and situations.
10. Can communicate effectively in speech and in writing.
11. Are able to learn independently and find relevant resources.
12. Are prepared for future changes in computer science and software engineering.
13. Are prepared to uphold professional and ethical standards.
14. Understand and appreciate the role of computer science and software engineering in a societal context.
15. Are aware of career and further educational opportunities.
16. Have a mature understanding of themselves and others

These RBE Educational Objectives reflect the expected accomplishments of WPI's graduates a few years after graduation. They are consistent with the mission and goal statements of WPI, the educational objectives of the RBE major as well as the ABET criteria for Accrediting Engineering Programs.

3.1.2 Section 3

This project will investigate the preparedness of WPI's undergraduate RBE program for ABET accreditation. This is a proper IQP because it is related to science and technology, a.k.a. the analysis of the RBE major, as well as a social need, a.k.a. the accreditation process. This is important for three reasons:

- To attract students to WPI
- Students want to know that they are graduating with an accredited major
- Employers want to hire people that graduated with an accredited major.

In order to fully examine the program, we will perform the following tasks:

- Develop a set of surveys to be posed to staff, students, and alumni of the RBE program.
- Submit surveys for approval by the human subject's office.
- Conduct surveys at the beginning of B term.
- Analyze data from the surveys and revise questions if necessary.
- Conduct surveys at the end of B term.
- Conduct surveys at the beginning of C term
- Analyze data from the surveys and revise questions if necessary.
- Conduct surveys at the end of C term
- Compile and analyze data from the surveys and compare against ABET criteria.
- Prepare findings and analysis and possible suggestions in a communicable format to improve likeliness of successful ABET accreditation.

The problem that we are handling indicated that we needed to get the students' perspectives on the course curriculum and how they believe they have advanced in the robotics major. To do this we focused primarily on the unified series and introductory robotics course, which is the core of the robotics program and what we believed to be the target of interest for ABET evaluation. The unified series consists of RBE 2001, 2002, 3001 and 3002, while the introductory robotics engineering course is RBE 1001. Each is designed to be an interdisciplinary approach to robotics, with faculty from the Mechanical Engineering, Computer Science, and Electrical and Computer Engineering departments teaching side-by-side.

To evaluate these courses, we administered surveys at the beginning and end of B-term and C-term in each unified course that was offered, as well as the introductory course. Administering two surveys allowed us to compare what the students felt they knew entering the course to what they felt they knew at the end of the course. The first survey consisted of questions from the syllabus of the class that they were just beginning so that we could better understand what each student already knew. The ending survey consisted of the same questions from the syllabus of the class they just finished. By doing this, we were able to observe if the students' perceived knowledge of course outcomes increased over the term. The goal was to be able to observe this increase in all categories because the syllabi state that the students should learn this material.

We also created a third survey for students who had already completed the unified series, in which they were asked questions regarding their opinions of the curriculum. This survey focused

mainly on determining whether or not the students felt they were being prepared for the real world. All of these surveys can be found in Appendix B.

The following is the timeline from our project:

Table 2

B-Term		
	Weeks 1-4	Conduct interviews and surveys of students and alumni
	Week 5	Compile and evaluate data. Make changes to questions or new questions if necessary.
	Weeks 5-7	Conduct further interviews and surveys.
C-Term		
	Weeks 1-2	Continue interviews and surveys if necessary.
	Weeks 3-5	Compile and analyze results.
	Weeks 5-7	Analyze results and draw conclusions. Prepare results and conclusions for final presentation.

The results from all the surveys were compiled based on course. Graphs were then produced, allowing for comparison of the before and after data. We were able to analyze each course outcome and look for weaknesses in the RBE program. From here we drew conclusions about the course outcomes and came up with recommendations as to how the courses could be improved. This would show ABET that if the courses were not up to standards, then there was definitely a plan for improvement-something they look for in Section 4 of the Self Study. Our analysis was conducted from A term through C term.

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4 Results

4.1 Surveys

In B term we conducted surveys of the RBE 1001: Introduction to Robotics Engineering, RBE 2002: Unified Robotics II, and RBE 3002: Unified Robotics IV courses. The purpose of these surveys was to gather information about the students' confidence in the robotics course objectives.

4.1.1 Introduction to Robotics Engineering

The results of the Introduction to Robotics Engineering surveys are shown in the following series of charts. In each chart, Survey 1 corresponds to the survey distributed at the beginning of the course, and Survey 2 to the survey distributed at the end of the course. The y-axis indicates the number of responses in each confidence level, and the x-axis indicates the confidence level response (with the exception of the first chart which displays question numbers on the x-axis). It is important to note that thirty-eight students took Survey 1, while thirty-six students took Survey 2. Each chart is also accompanied by a brief description of what the chart shows and the important information that can be drawn from it.

The first chart shown below (Figure 1) is a graphical representation of the average responses from students in the Introduction to Robotics Engineering course in B term 2009. The error bars displayed represent the standard deviation of the data, indicating that over 68% of responses were within the error bars. The data in this chart shows us that student confidence increased in all areas, shown by the higher level of the Survey 2 average responses, and smaller error bars.
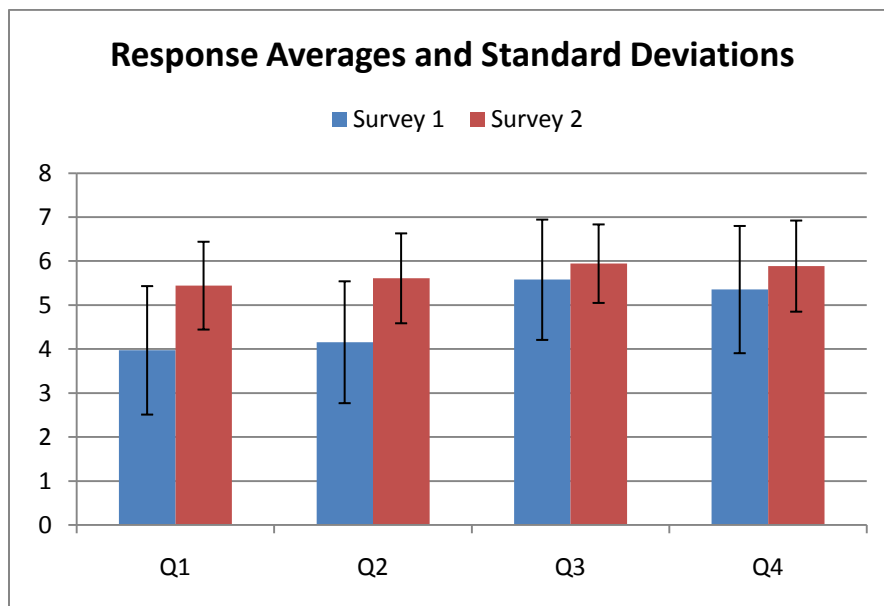

Figure 1

The table below contains the survey question topics corresponding to questions Q1 through Q10d in the Average Results chart shown above. Each question began with "How confidently do you feel that you could…," asking students to rate their confidence level on a scale from 1-7.

Table 3

Question Number	Question
Q1	Design the electrical component of a robot?
Q2	Design the control component of a robot?
Q3	Design the software component of a robot?
Q4	Design the mechanical component of a robot?

The graph below (Figure 2) represents the students' responses to the survey question: How confidently do you feel you could design the electrical component of a robot to meet a specific objective? This question was created to investigate the first part of Course Objective 2 of the RBE 1001 syllabus which states: It is expected that by the end of this course the student will be able to specify the electrical and control design of a robot to meet a specific design objective. At the end of the course, significantly more students responded with a confidence level of 6. There was also only one response below confidence level 4.
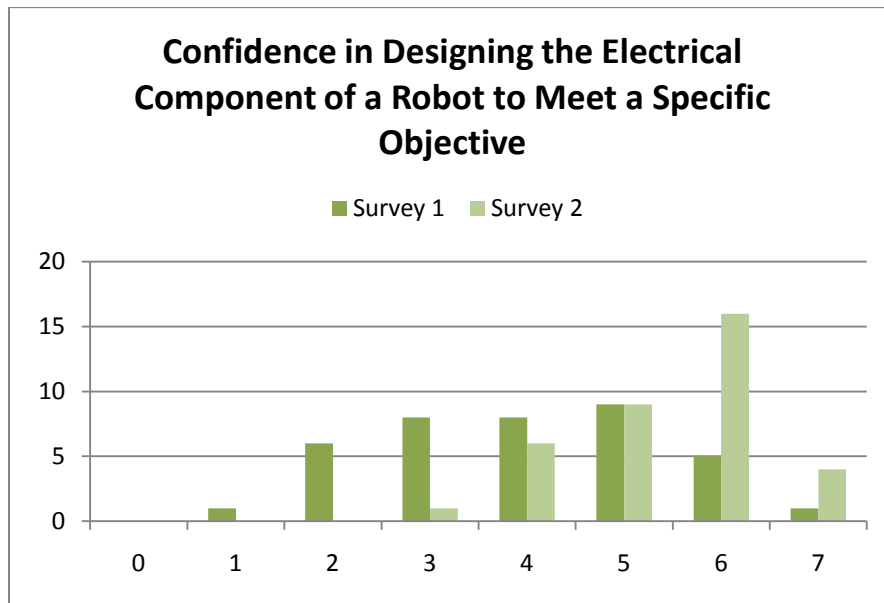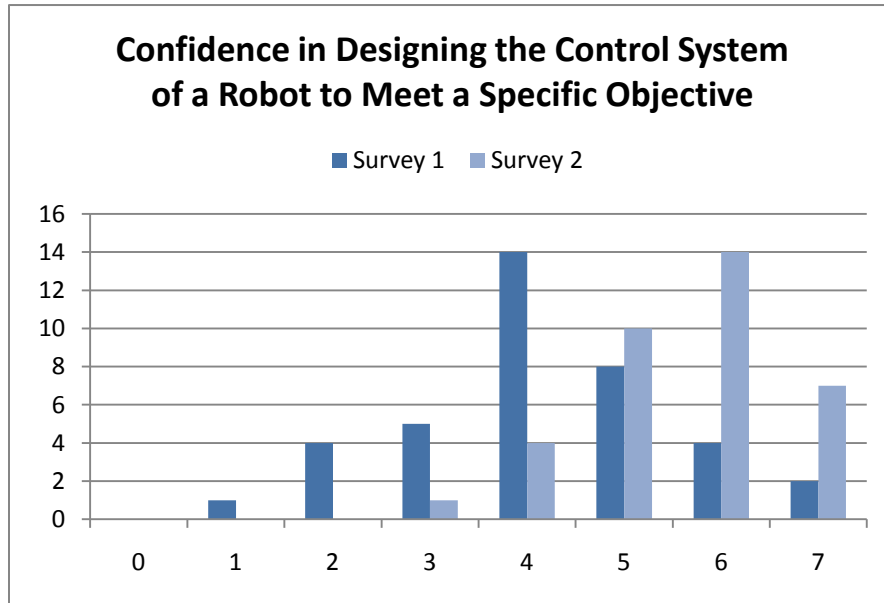

Figure 2

The graph below (Figure 3) represents the students' responses to the survey question: How confidently do you feel you could design the control component of a robot to meet a specific objective? This question was created to investigate the second part of Course Objective 2 of the RBE 1001 syllabus which states: It is expected that by the end of this course the student will be able to specify the electrical and control design of a robot to meet a specific design objective. At the end of the course, there was only one response below confidence level 4, and the most responses were at confidence level 6. This shows a great increase in class confidence in designing the control system of a robot.
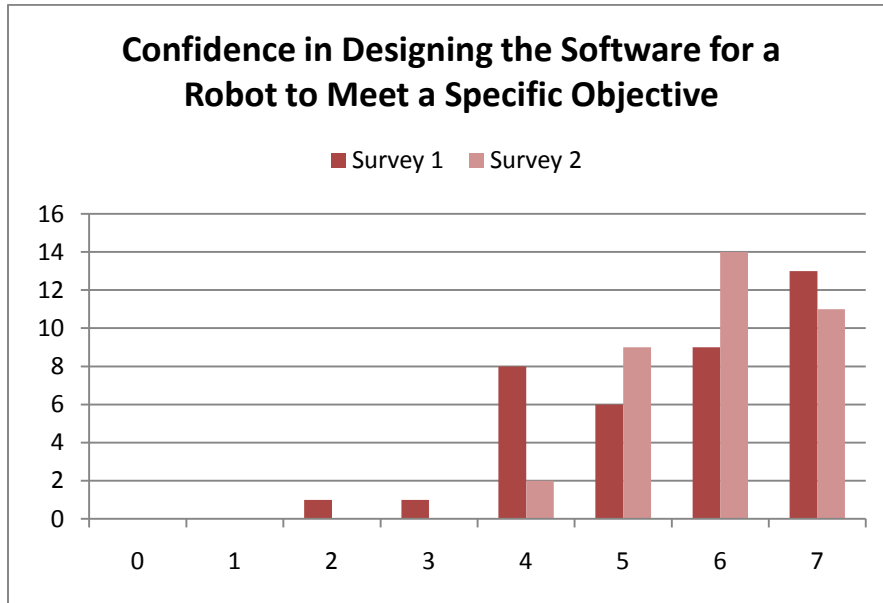

Figure 3

The graph below (Figure 4) represents the students' responses to the survey question: How confidently do you feel you could design the software component of a robot to meet a specific objective? This question was created to investigate Course Objective 3 of the RBE 1001 syllabus which states: It is expected that by the end of this course the student will be able to specify the software design of a robot to meet a specific design objective. At the end of the course, the most number of students responded with a confidence level of 6. There were also only 2 responses below confidence level 5.

Figure 4

The graph below (Figure 5) represents the students' responses to the survey question: How confidently do you feel you could design the mechanical component of a robot to meet a specific objective? This question was created to investigate Course Objective 4 of the RBE 1001 syllabus which states: It is expected that by the end of this course the student will be able to specify the mechanical design of a robot to meet a specific design objective. At the end of the course, most students responded with a confidence level of 6 or 7, and only 1 student responded with a confidence level below 4.
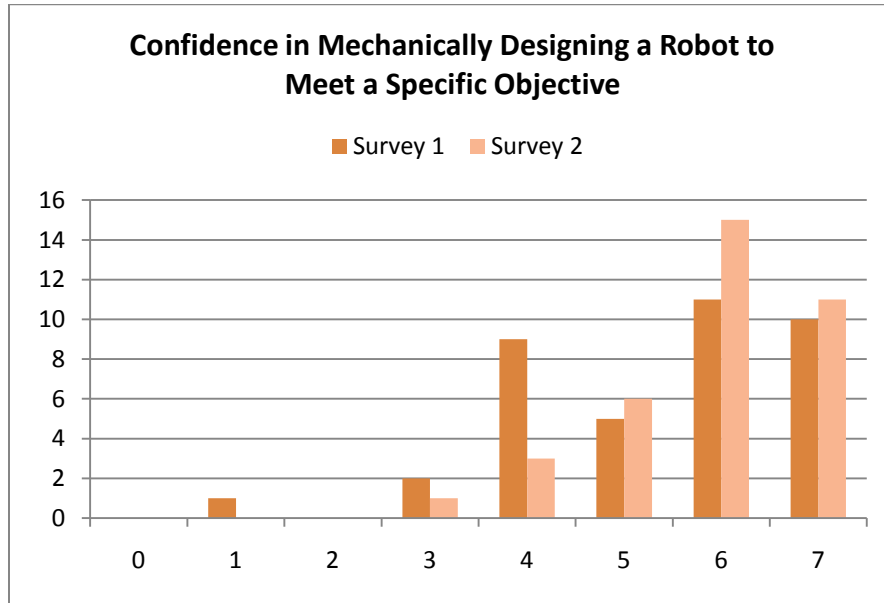

Figure 5

The graph below (Figure 6) depicts the results from Survey 1 in the previous four charts on the same axis. This shows that many more students claimed to be more confident in mechanical and software design than control system and electrical design at the beginning of the course.
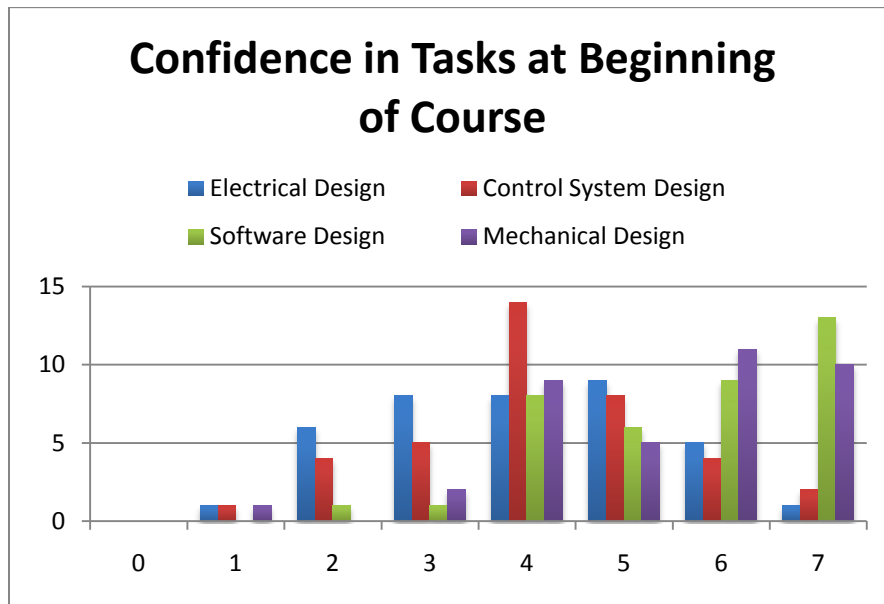

Figure 6

The graph below (Figure 7) depicts the results from Survey 2 in the previous four charts on the same axis. This shows that most students indicated a confidence level of 6 in all areas of design at the end of the course; however, the number of confidence level 7 responses were still lower in electrical and control system design than in mechanical and software design.
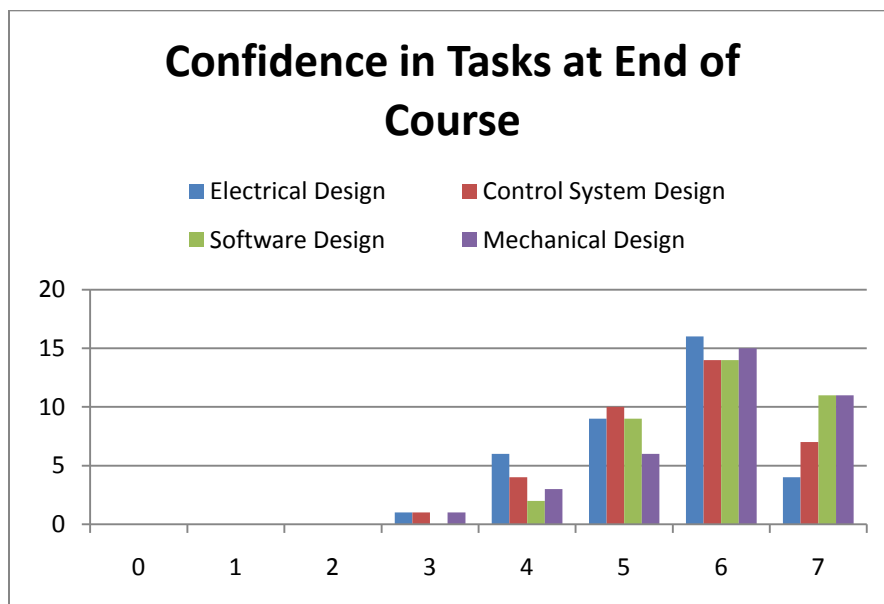

Figure 7

4.1.2 Unified Robotics I

In C Term, we distributed surveys to students in the Unified Robotics I course. The charts and their corresponding descriptions below display the results of the first survey (Survey 1) given to this course at the beginning of the term, and the second survey (Survey 2) given at the end of the term. It is important to note that in Survey 1, 33 surveys were completed while in Survey 2 only 18 surveys were completed.

The first chart shown below (Figure 8) is a graphical representation of the average responses from students in the Unified Robotics I course in C term 2010. The error bars displayed represent the standard deviation of the data, indicating that over 68% of responses were within the error bars. The data in this chart shows us that student confidence increased in all areas, shown by the higher level of the Survey 2 average responses, and smaller error bars.
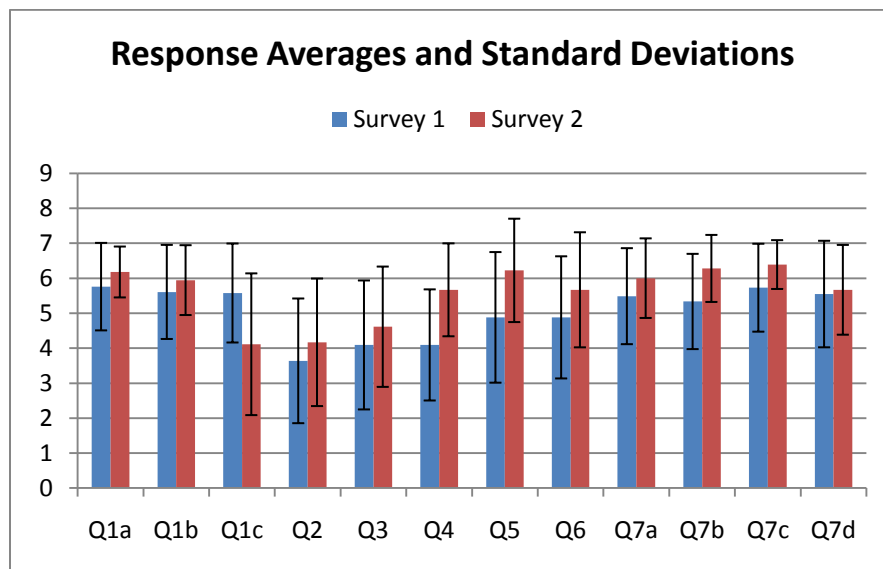

Figure 8

The questions from the survey that correspond to Q1a through Q7c in the chart above are displayed in the table below. Each question was prefaced by "How confidently do you feel you could…."

Question Number	Question
Q1a	Formulate the position in a simple mechanism.
Q1b	Formulate the velocity in a simple mechanism.
Q1c	Formulate the acceleration in a simple mechanism.
Q2	Determine the power system requirements using force analysis.
Q3	Determine structural requirements using force analysis.
Q4	Specify DC motor requirements for a robot.
Q5	Write moderately involved programs in C for a robot.
Q6	Create an electrical system to convert battery energy into a signal to drive a DC motor.
Q7a	Construct a mobile robotic system to perform a specified task.
Q7b	Program a mobile robotic system to perform a specified task.
Q7c	Test the operation of a mobile robotic system to perform a specified task.

The graph below (Figure 9) depicts Unified Robotics I students' response to the survey question which asked: How confidently do you feel you could formulate the position in a simple mechanism? This question was created to investigate part of Course Objective 2 in the RBE 2001 syllabus, which states: upon the completion of this course students will be able to formulate the position, velocity and acceleration kinematics of simple mechanisms. The distribution of responses is concentrated in the upper half of the possible responses. This indicates that general confidence level of the class in this area at the beginning of the course was relatively high. At the end of the course, no students responded with a confidence level below 5; however, there were more 6 level responses than 7 level responses. We attribute this to students possibly gaining a better understanding of what is involved in formulating position, and therefore feeling slightly less confident. This can still be taken as an improvement in the course.
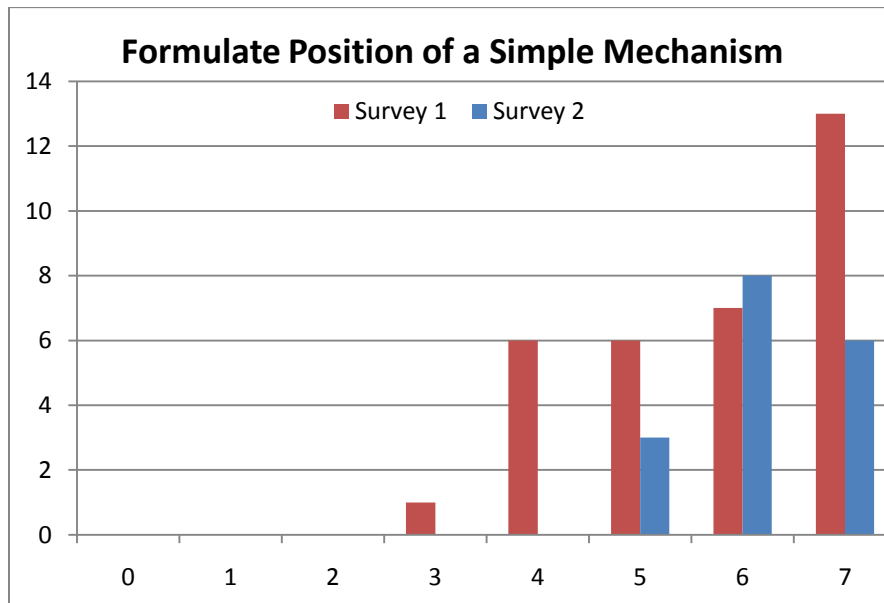

Figure 9

The graph below (Figure 10) shows Unified Robotics I students' response to the survey question which asked: How confidently do you feel you could formulate the velocity in a simple mechanism? This question was created to investigate part of Course Objective 2 in the RBE 2001 syllabus, which states: upon the completion of this course students will be able to formulate the position, velocity and acceleration kinematics of simple mechanisms. The results display that the class was moderately confident in this area. The outliers lay one each in the 2 and 3 confidence levels. At the end of the course, there was still only one response of confidence level 3, and all other responses were 5 or higher. There was again a shift in 6 and 7 level responses, resulting in almost twice the number of 6 responses as 7 responses.
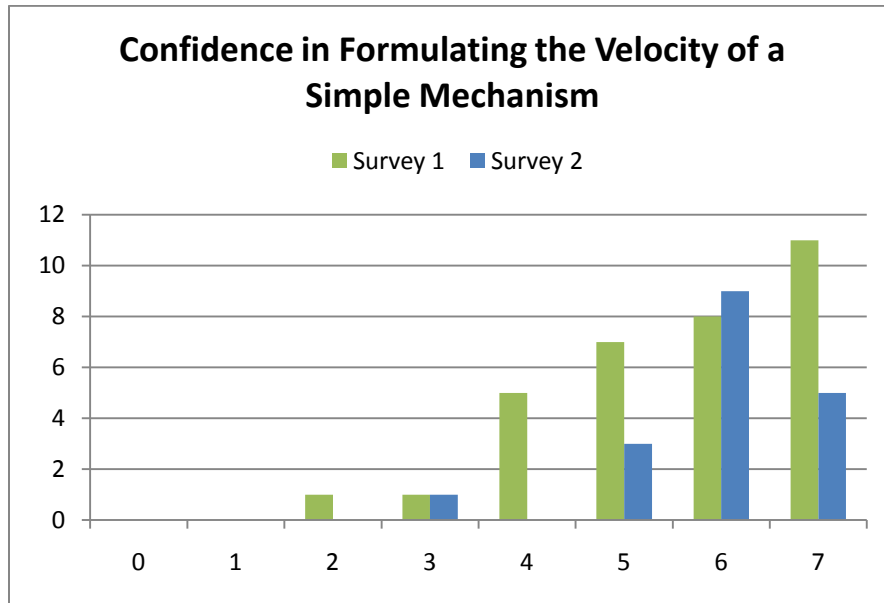

Figure 10

The graph below (Figure 11) represents Unified Robotics I students' response to the survey question which asked: How confidently do you feel you could formulate the acceleration in a simple mechanism? This question was created to investigate part of Course Objective 2 in the RBE 2001 syllabus, which states: upon the completion of this course students will be able to formulate the position, velocity and acceleration kinematics of simple mechanisms. The results from this question display a more spread out distribution than some of the other questions asked in this survey at the beginning of the course; however, significantly more students were very confident than the number of students that were not quite confident. At the end of the course there were more low confidence responses than high confidence responses. This indicates that students may have discovered what this process entails, and gained a more realistic idea of their ability to formulate the acceleration of a simple mechanism.
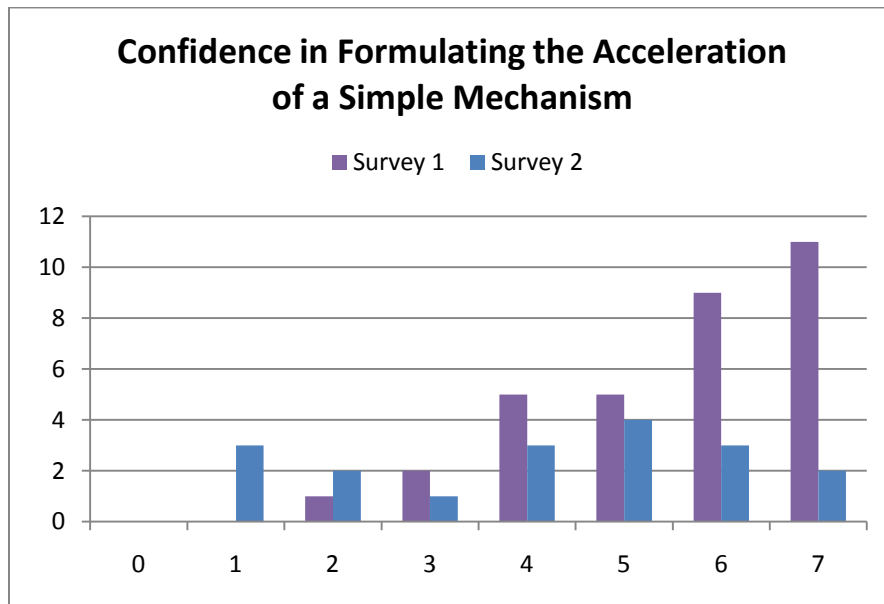

Figure 11

The graph below (Figure 12) represents Unified Robotics I students' response to the survey question which asked: How confidently do you feel you could determine power system requirements using force analysis? This question was created to investigate part of Course Objective 3 in the RBE 2001 syllabus, which states: upon the completion of this course students will be able to determine power system requirements and structural requirements using force analysis. There is a concentration of students who gave a neutral response of confidence level 4, with the general distribution reflecting that most students were not confident in the area. The distribution in the second survey is approximately the same as the distribution in the first survey, with the exception of a higher percentage of students giving a response of 5, and lower percentage with a response of 2.
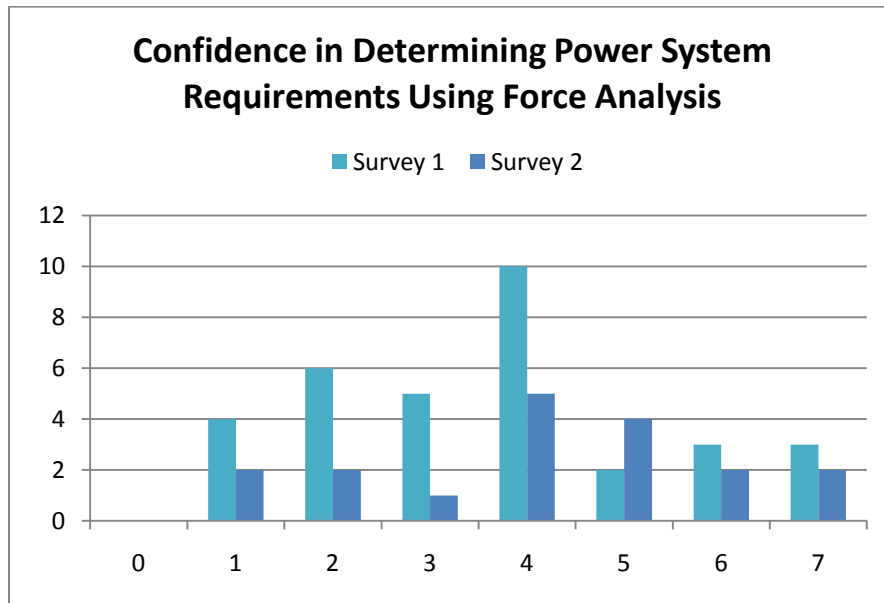

Figure 12

The graph below (Figure 13) represents Unified Robotics I students' response to the survey question which asked: How confidently do you feel you could determine structural requirements using force analysis? This question was created to investigate part of Course Objective 3 in the RBE 2001 syllabus, which states: upon the completion of this course students will be able to determine power system requirements and structural requirements using force analysis. As depicted in the graph below, many students did not feel confident in determining structural requirements in the beginning of the course. A large number of people responded with a confidence level of 2, 5 or 6. At the end of the course, there was a higher percentage of responses at levels 4 and 7, and a lower percentage or responses at levels 1 and 2.
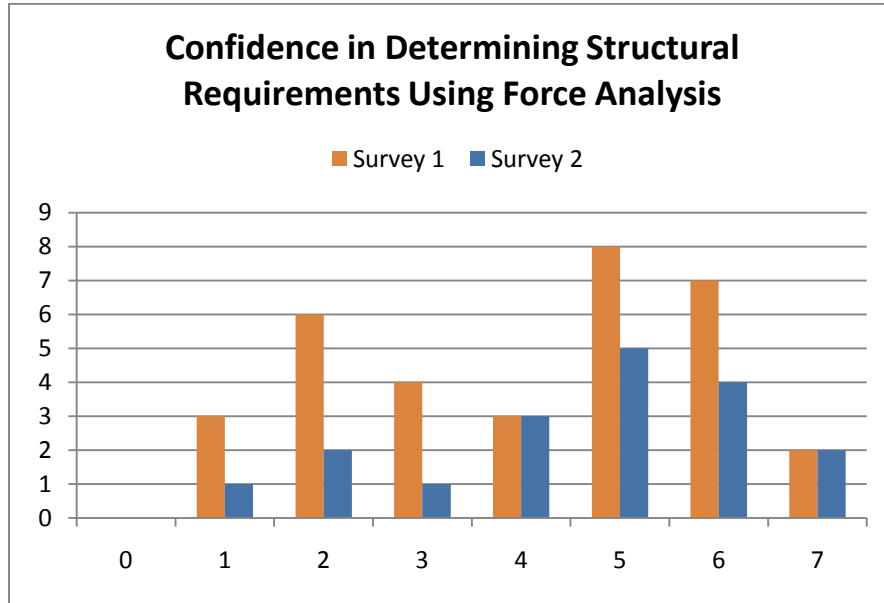

Figure 13

The graph below (Figure 14) represents Unified Robotics I students' response to the survey question which asked: how confidently do you feel you could specify DC motor requirements for a robot? This question was created to investigate part of Course Objective 4 in the RBE 2001 syllabus, which states: upon the completion of this course students will be able to specify DC motor requirements that meet a specified locomotion or manipulation task. The responses from students regarding their confidence in this area at the beginning of the course resulted in a relatively normal distribution. The primary outlier from the curve is the high number of responses of confidence level 5. At the end of the course, there was a much greater percentage of responses at levels 6 and 7, and only one response below confidence level 4.
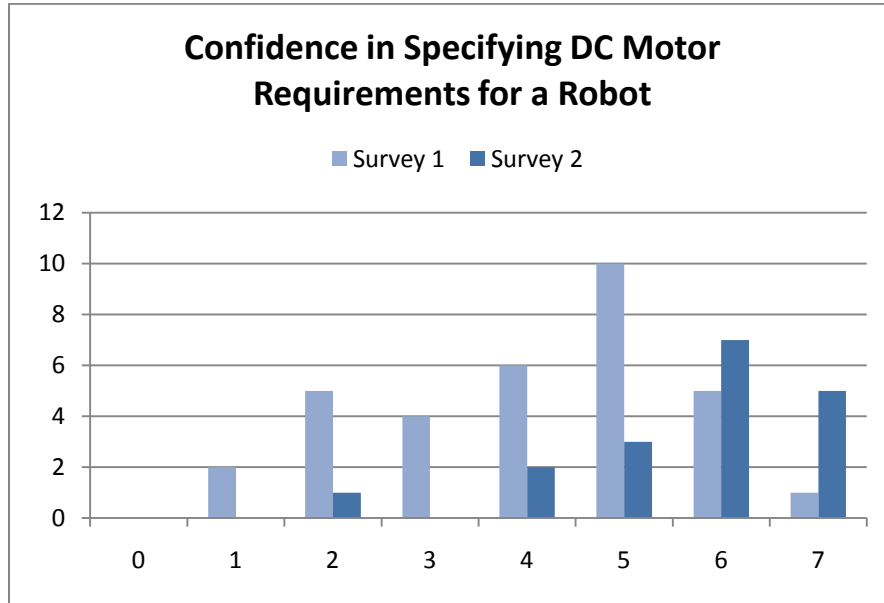

Figure 14

The graph below (Figure 15) represents Unified Robotics I students' response to the survey question which asked: How confidently do you feel you could write moderately involved programs in C for a robot? This question was created to investigate part of Course Objective 5 in the RBE 2001 syllabus, which states: upon the completion of this course students will be able to write moderately involved programs in C to perform a specified task with a robotic system in real-time. A significant number of students responded with confidence level of 6 and 7 in regards to writing C programs to control a robot. The lower confidence responses were fewer, and of relatively normal distribution. A the end of the course, almost all of the responses were of level 6 or 7, with only three responses lower than confidence level 6.
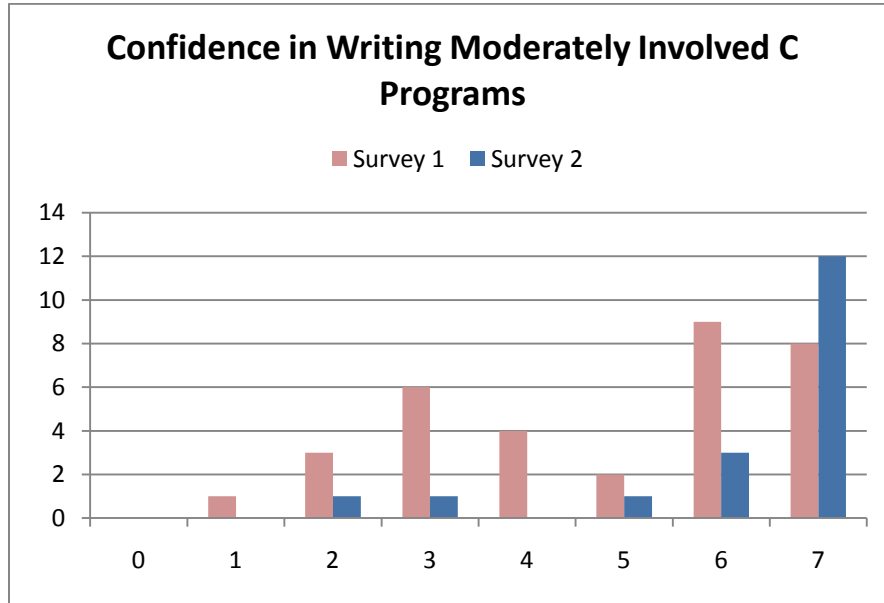

Figure 15

The graph below (Figure 16) represents Unified Robotics I students' response to the survey question which asked: How confidently do you feel you could create an electrical system to convert battery energy into a signal to drive a DC motor? This question was created to investigate part of Course Objective 6 in the RBE 2001 syllabus, which states: upon the completion of this course students will be able to specify appropriate electrical system design to convert battery energy into a controllable power drive signal to a specified DC motor. The general trend shows that many students were quite confident in this area in the beginning of the course, with the majority responding with a confidence level of 5, 6 or 7. At the end of the course, only three students responded with a confidence level below 5, and more students responded with 7, than with 6 or 5.
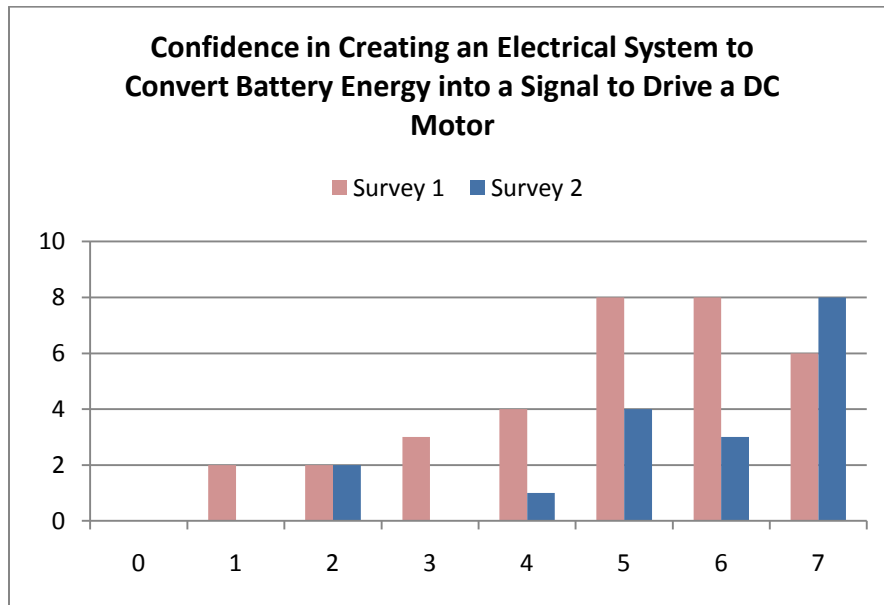
Confidence in Creating an Electrical System to Convert Battery Energy into a Signal to Drive a DC Motor

Survey 1   Survey 2

Figure 16

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The graph below (Figure 17) represents Unified Robotics I students' response to the survey question which asked: How confidently do you feel you could construct a mobile robotic system to perform a specified task? This question was created to investigate part of Course Objective 7 in the RBE 2001 syllabus, which states: upon the completion of this course students will be able to construct, program, and test the operation of a mobile robotic system to perform a specified task. The figure indicates that the majority of students in the Unified Robotics I course were fairly confident in their abilities to construct a robot at the beginning of the course. At the end of the course, a greater percentage of students responded with a 6 or 7, and significantly smaller percentage responded with a 3, 4 or 5.
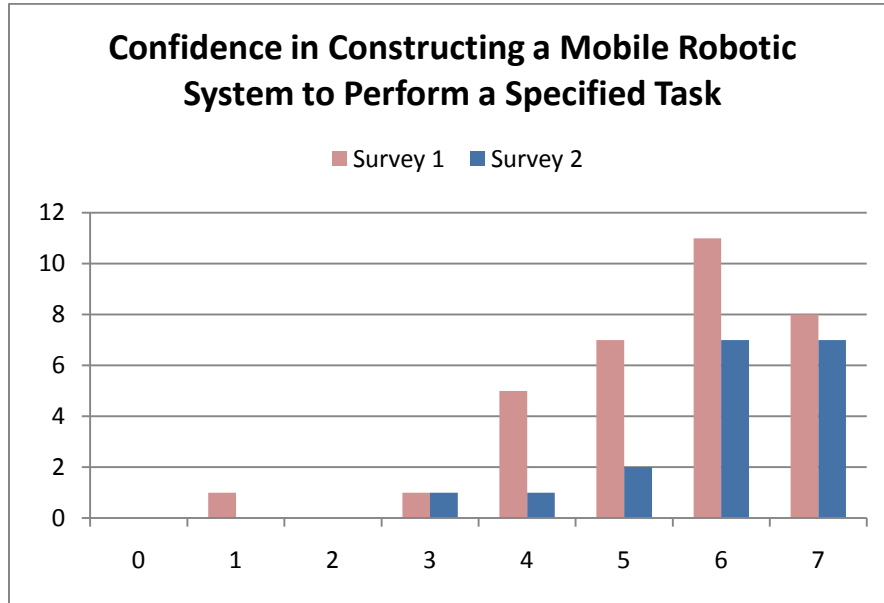

Figure 17

The graph below (Figure 18) represents Unified Robotics I students' response to the survey question which asked: How confidently do you feel you could program a mobile robotic system to perform a specified task? This question was created to investigate part of Course Objective 7 in the RBE 2001 syllabus, which states: upon the completion of this course students will be able to construct, program, and test the operation of a mobile robotic system to perform a specified task. The results shown below indicate that the majority of students were quite confident in their ability to program a robot at the beginning of the course. At the end of the course, only two students responded with a confidence level below 6. This shows a significant increase in the overall confidence of students in the course in the area of programming.

Figure 18

The graph below (Figure 19) represents Unified Robotics I students' response to the survey question which asked: How confidently do you feel you could test the operation of a mobile robotic system to perform a specified task? This question was created to investigate part of Course Objective 7 in the RBE 2001 syllabus, which states: upon the completion of this course students will be able to construct, program, and test the operation of a mobile robotic system to perform a specified task. As shown in the chart below, the results from the survey administered at the beginning of the term indicate that students were confident in testing a robot. At the end of the course, no students responded with a confidence level below 5, and most students responded with a 6 or 7 level of confidence in testing a robot.
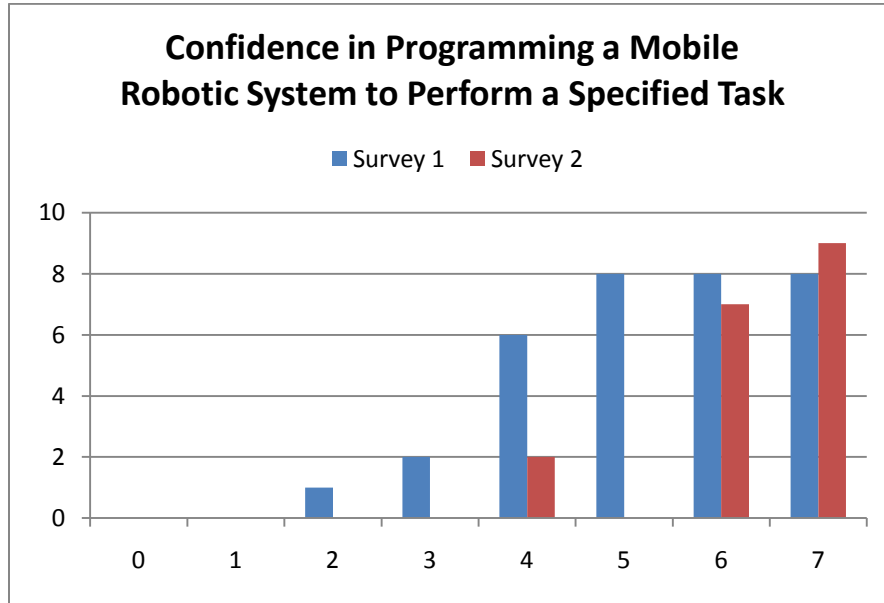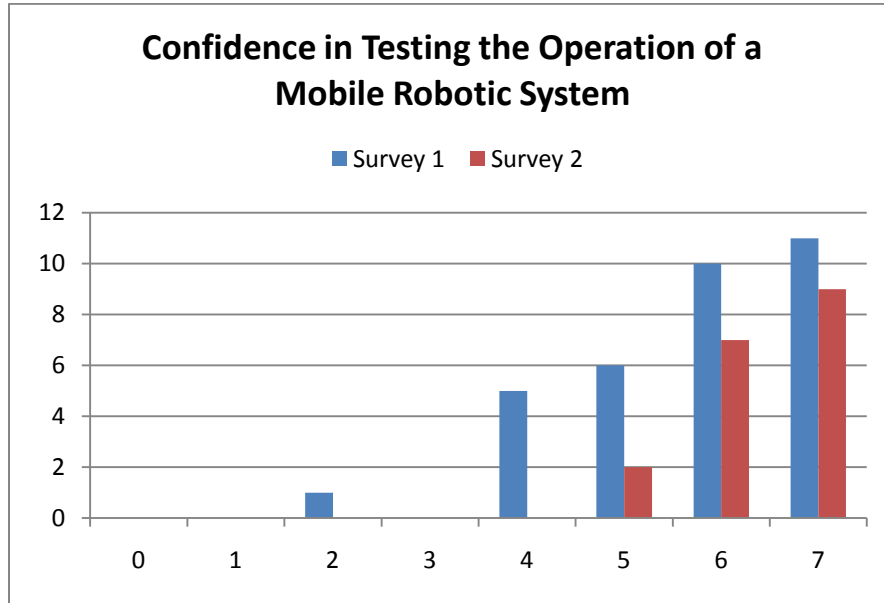

Figure 19

The graph below (Figure 20) represents Unified Robotics I students' response to the survey question which asked: How confidently do you feel you could wire a robot? This question was created to investigate part of Course Objective 7 in the syllabus, which states: upon the completion of this course students will be able to construct, program, and test the operation of a mobile robotic system to perform a specified task. The chart below shows the level of confidence students indicated in regards to wiring a robot. At the beginning of the course, the majority of students were very confident about wiring robots, while three students responded with a confidence level of only 1 or 2. At the end of the course, only three students responded with a confidence level below 5. This again shows an increase in student confidence in wiring a robot.
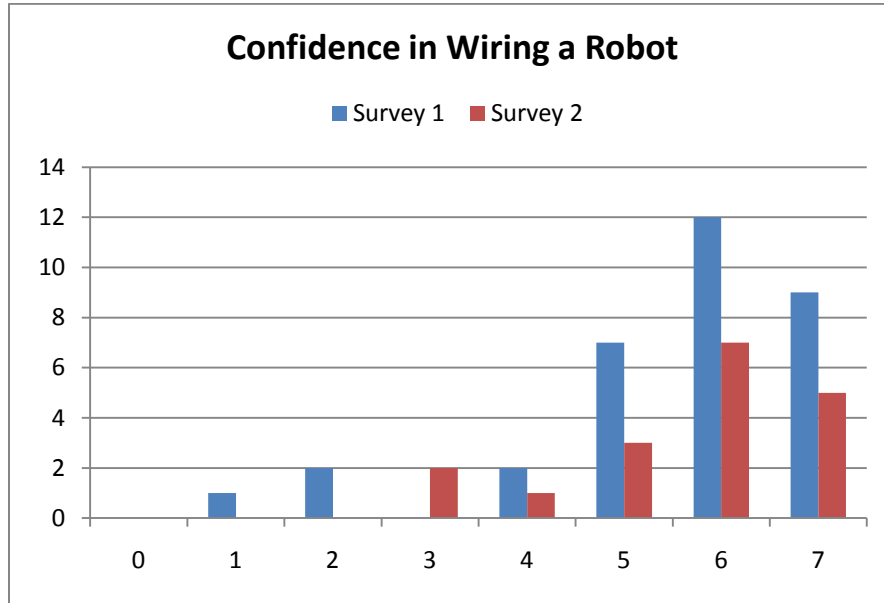
Figure 20

The figure below (Figure 21) is a compilation of the previous four graphs. This graph compares the students' indicated confidence in constructing, programming, testing and wiring robots to complete a given task at the beginning of the Unified Robotics I course. Looking at the graph shows us that the confidence levels are only slightly sporadic between the four different categories, and there are significantly more response of confidence between 4 and 7 than between 1 and 3.
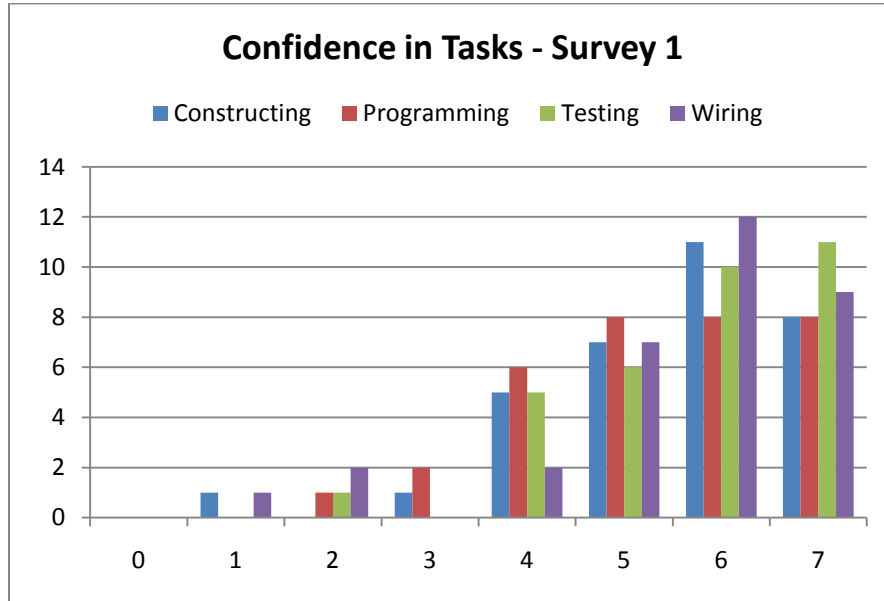
Figure 21

The figure below (Figure 22) is a compilation of the previous four graphs. This graph compares the students' indicated confidence in constructing, programming, testing and wiring robots to complete a given task at the end of the Unified Robotics I course. Looking at the graph shows us that the confidence levels are now quite even between the four different categories. There are also no responses below confidence level 3, and very few from 3 to 5. The responses are greatly concentrated in the 6 and 7 confidence levels.
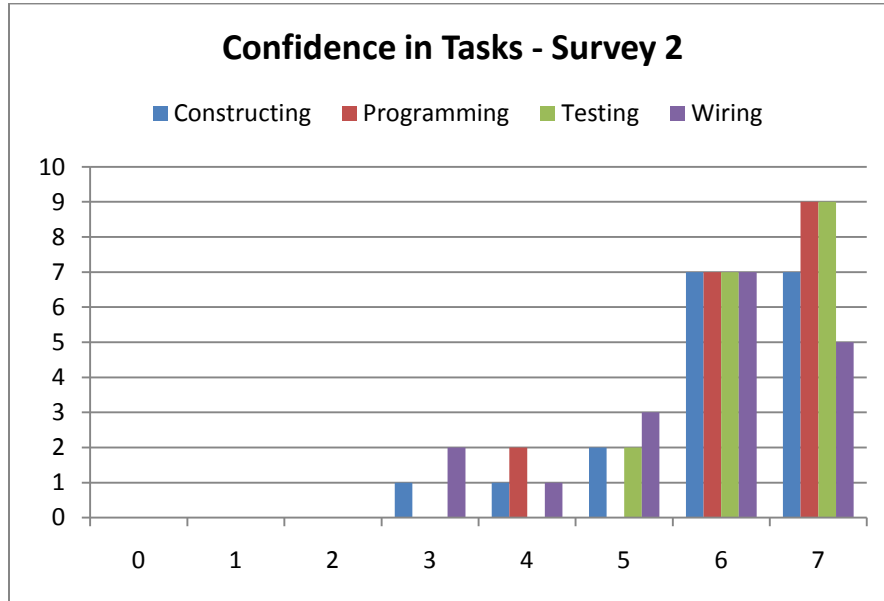
Figure 22

4.1.3 Unified Robotics II

The results of the Unified Robotics II surveys are shown in the charts below. In each chart, Survey 1 corresponds to the survey distributed at the beginning of the course, and Survey 2 to the survey distributed at the end of the course. The y-axis indicates the number of responses in each confidence level, and the x-axis indicates the confidence level response (with the exception of the first chart which displays question numbers on the x-axis). It is important to note that thirty-six students took Survey 1, while only thirty students took Survey 2. Each chart is also accompanied by a brief description of what the chart shows and the important information that can be drawn from it.

The chart shown below (Figure 23) is a graphical representation of the average responses from students in the Unified Robotics II course in B term 2009. The error bars displayed represent the standard deviation of the data, indicating that over 68% of responses were within the error bars. The data in this chart shows us that average student confidence increased in all areas, shown by the higher level of the survey 2 average responses; however, the error bars increased, showing that students gave a wider variety of high confidence responses.
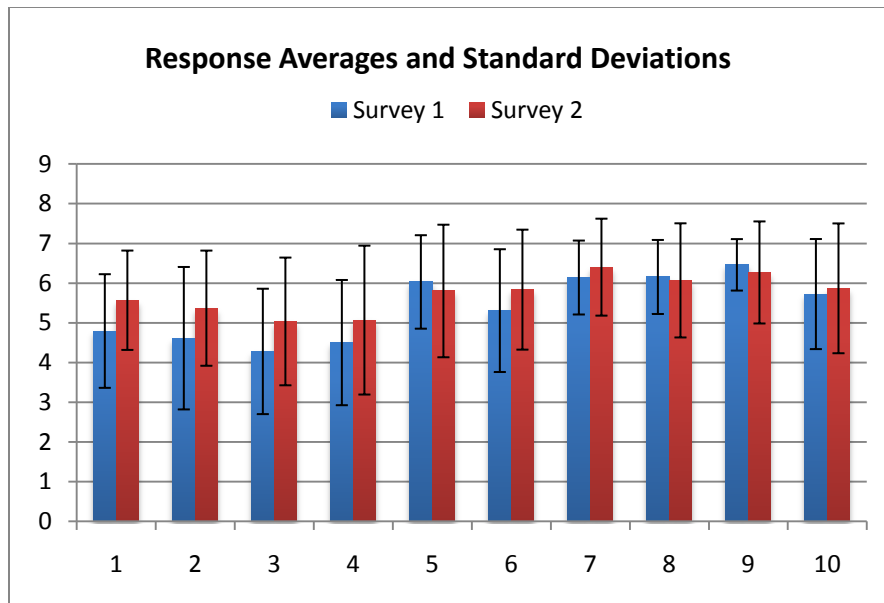
Figure 23

The table below contains the survey question topics corresponding to questions 1-10 in the Average Results chart shown above. Each question began with "How confidently do you feel that you could…," asking students to rate their confidence level on a scale from 1-7.

Table 4

Number	Topic
1	Apply concepts of stress and strain related to force in robotics applications.
2	Analyze sensor signals for signal conditioning.
3	Design electronic circuits for signal conditioning.
4	Implement algorithms for signal conditioning.
5	Write moderately involved programs in C for a robot.

6	Creating an electrical system to convert battery energy into a signal to drive a DC motor.
7	Constructing a mobile robotic system to perform a specified task.
8	Programming a mobile robotic system to perform a specified task.
9	Testing the operation of a mobile robotic system to perform a specified task.
10	Wiring a robot.

This graph (Figure 24, below) represents the students' responses to the survey question: How confidently do you feel that you could apply concepts of stress and strain as related to force in robotics applications? This question was created to investigate Course Objective 1 of the RBE 2002 syllabus which states: upon completion of this course, students will be able to apply concepts of stress and strain as related to sensing of force in robotics applications. The distribution of the bars in the below chart indicates that overall student understanding improved between the administering of the first and second surveys. All but two students responded to this question with a 5, 6 or 7. This too, indicates that it is valid to assume the class in general felt they understood this topic.

Figure 24

The next chart (Figure 25) represents the students' responses to the survey question: How confidently do you feel that you could analyze sensor signals for signal conditioning? This question was created to investigate part of Course Objective 3 of the RBE 2002 syllabus which states: upon completion of this course, students will be able to analyze sensor signals and design electronic circuits and/or implement algorithms for signal conditioning. The distribution in this chart is similar to the previous in the distribution of its Survey 2 responses. It is clear in the differences between the results of the two surveys, that students felt they learned the material required to meet this course objective.

Figure 25

The next chart (Figure 26) represents the students' responses to the survey question: How confidently do you feel that you could design electronic circuits for signal conditioning? This question was created to investigate part of Course Objective 3 of the RBE 2002 syllabus which states: upon completion of this course, students will be able to analyze sensor signals and design electronic circuits and/or implement algorithms for signal conditioning. The responses for the second survey were much higher than the first survey; however there were also more neutral responses and fewer lower responses. The chart shows that there was a shift from lower and neutral responses, to neutral and higher responses by the end of the course.
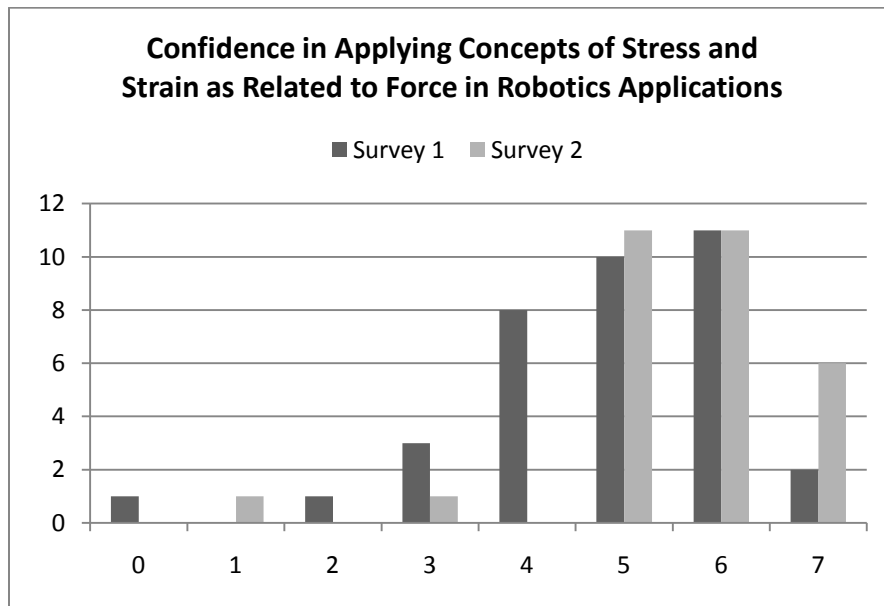

Figure 26

53

The next chart (Figure 27) represents the students' responses to the survey question: How confidently do you feel that you could implement algorithms for signal conditioning? This question was created to investigate part of Course Objective 3 of the RBE 2002 syllabus which states: upon completion of this course, students will be able to analyze sensor signals and design electronic circuits and/or implement algorithms for signal conditioning. The first survey responses were mostly neutral with more higher responses than lower ones. The second survey had approximately the same number of low responses as the first survey, but it had more high responses and fewer neutral responses than the first survey.

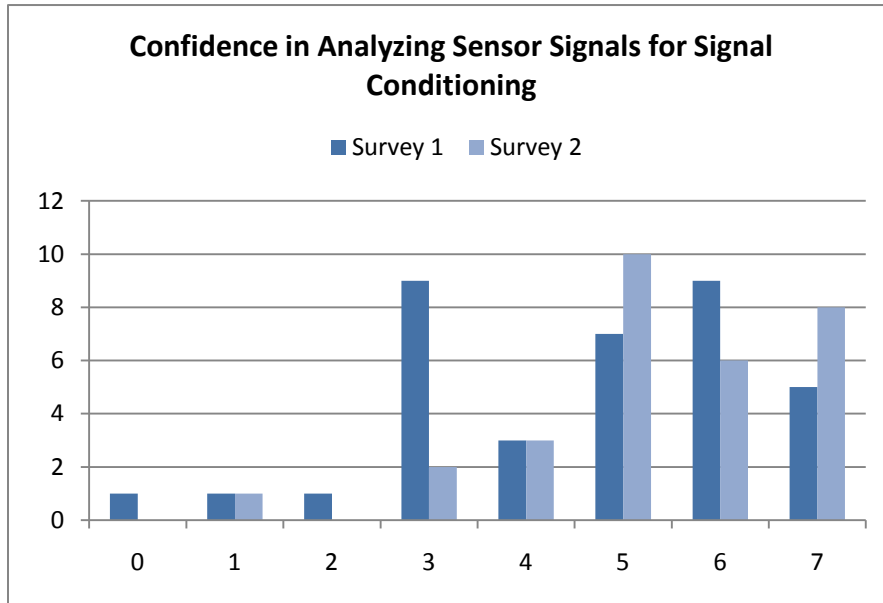**Figure 27**

The next chart (Figure 28) represents the students' responses to the survey question: How confidently do you feel that you could write moderately involved programs in C for a robot? This question was created to investigate part of Course Objective 4 of the RBE 2002 syllabus which states: upon completion of this course, students will be able to write moderately involved programs in C to perform a specified task with a robotic system in real-time. Responses on the second survey were lower overall than the responses on the first survey. Fewer people gave high responses, but a larger percentage of people gave high responses. In the second survey, more people responded low than on the first survey.

Figure 28

The next chart (Figure 29) represents the students' responses to the survey question: How confidently do you feel that you could create an electrical system to convert battery energy into a signal to drive a DC motor? This question was created to investigate part of Course Objective 4 of the RBE 2002 syllabus which states: upon completion of this course, students will be able to write moderately involved programs in C to perform a specified task with a robotic system in real-time. Overall from the first survey to the second, there was a shift in responses from lower to higher. For the first survey, the responses ranged mostly from neutral to high. In the second survey, the responses were mostly high, with very few neutral or low responses.
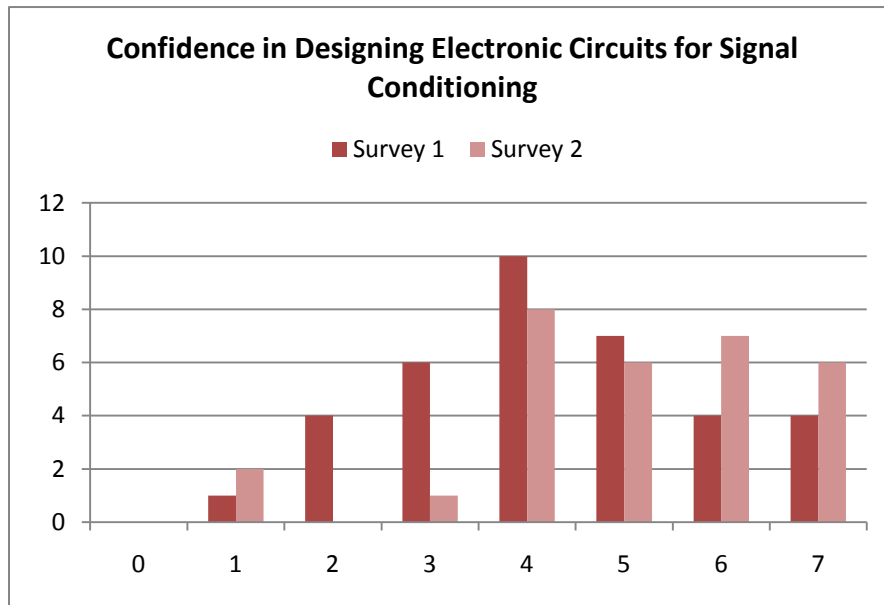

Figure 29

The next chart (Figure 30) represents the students' responses to the survey question: How confidently do you feel that you could construct a mobile robotic system to perform a specified task? This question was created to investigate part of Course Objective 5 of the RBE 2002 syllabus which states: upon completion of this course, students will be able to construct, program, and test the operation of a robotic system to perform a specified task. There were the same number of low responses in both surveys, but the low response in the second survey was significantly lower than the low response in the first survey. In the second survey, there were more responses that were the highest, but there were fewer of the neutral responses.
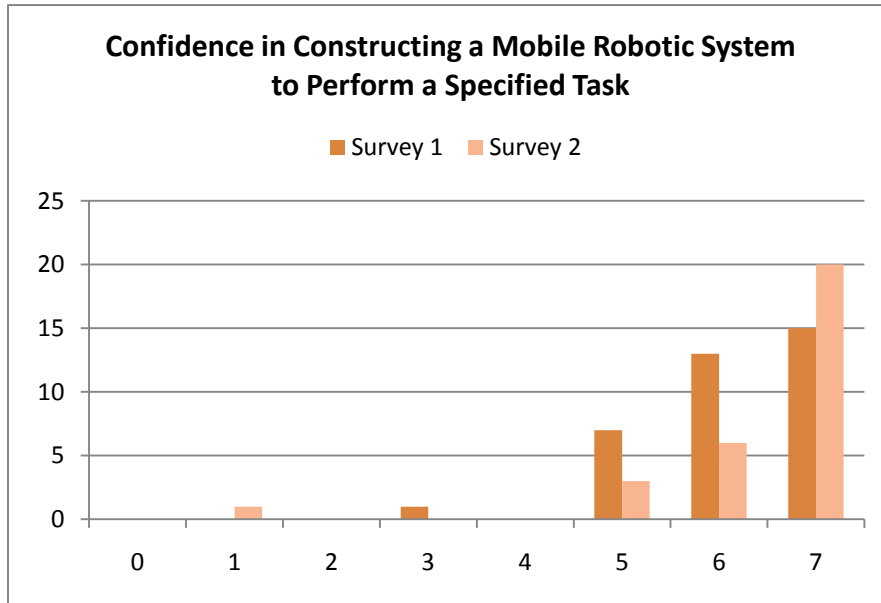
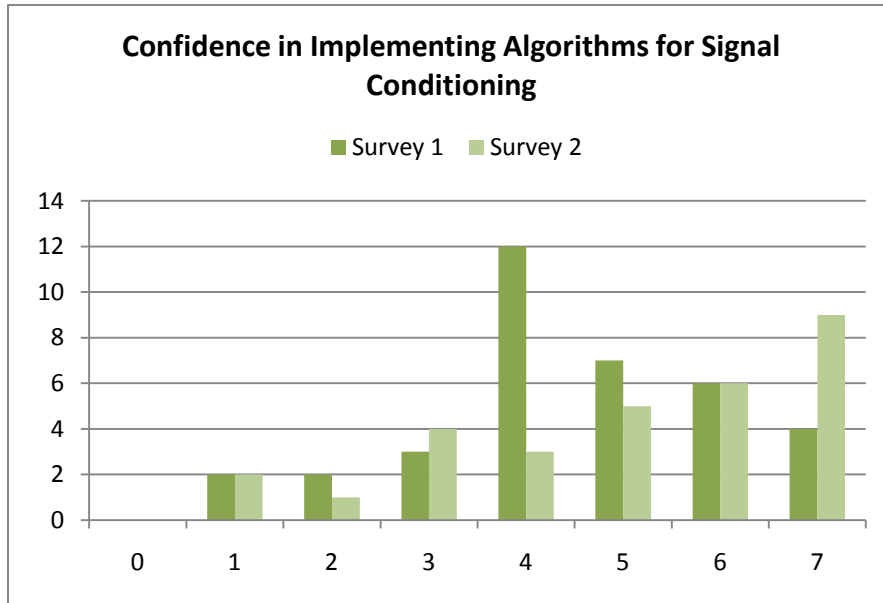**Figure 30**

The next chart (Figure 31) represents the students' responses to the survey question: How confidently do you feel that you could program a mobile robotic system to perform a specified task? This question was created to investigate part of Course Objective 5 of the RBE 2002 syllabus which states: upon completion of this course, students will be able to construct, program, and test the operation of a robotic system to perform a specified task. There were more low responses in the second survey than in the first survey. More students responded with the highest confidence in the second survey than in the first.
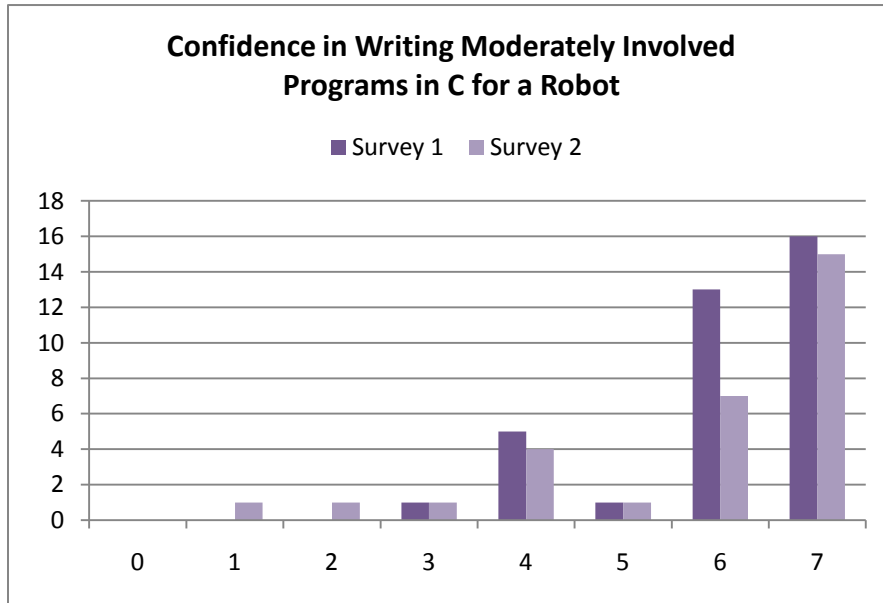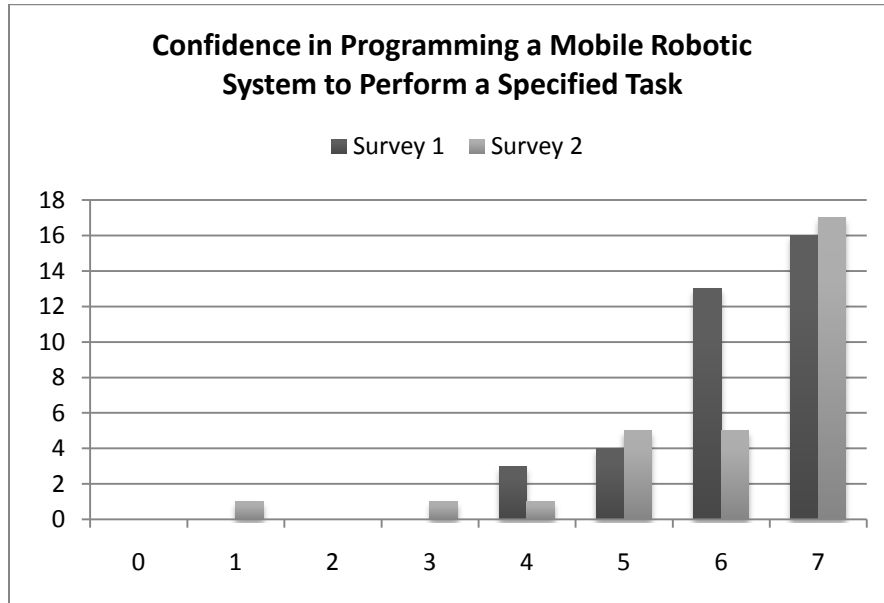

Figure 31

The next chart, (Figure 32) represents the students' responses to the survey question: How confidently do you feel that you could test the operation of a mobile robotic system to perform a specified task? This question was created to investigate part of Course Objective 5 of the RBE 2002 syllabus which states: upon completion of this course, students will be able to construct, program, and test the operation of a robotic system to perform a specified task. The responses for the second survey were slightly less positive compared to the first survey. The chart emphasizes that there is some discrepancy by the students, but it still shows that the students gained confidence from the specified curriculum.
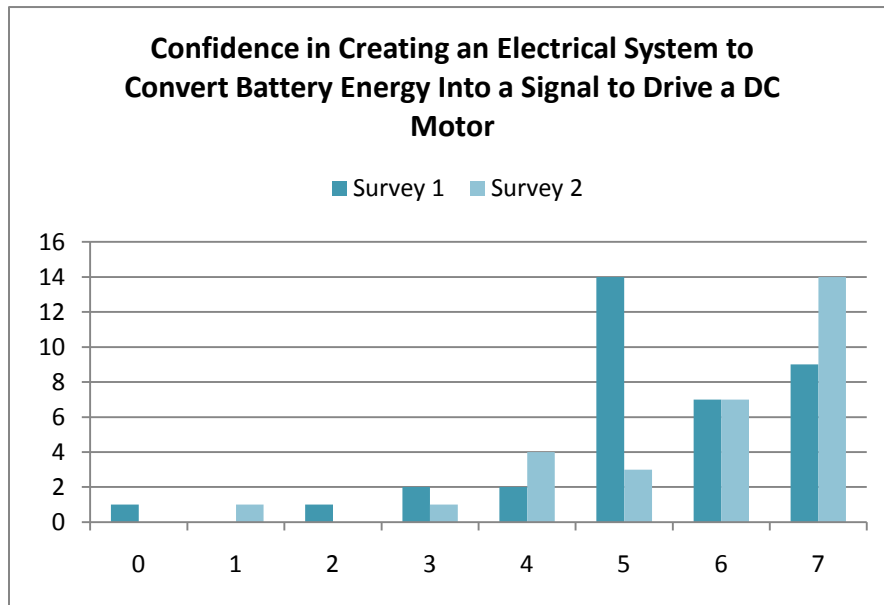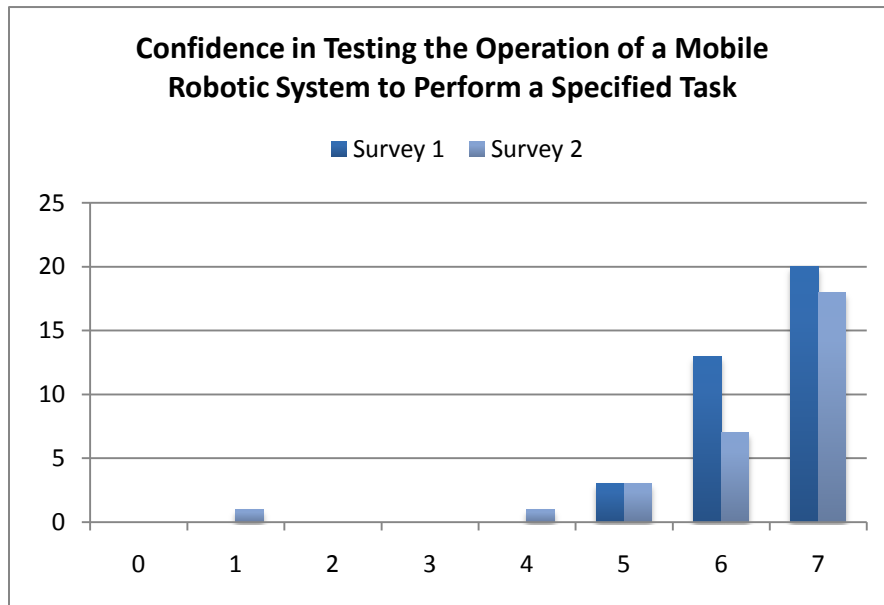

Figure 32

The next chart, (Figure 33) represents the students' responses to the survey question: How confidently do you feel that you could wire a robot (ECE component)? This question was created to investigate part of Course Objective 5 of the RBE 2002 syllabus which states: upon completion of this course, students will be able to construct, program, and test the operation of a robotic system to perform a specified task. The responses for the second survey were even more positive than the first survey, but most of the students for both surveys felt like they understood this part of the curriculum.
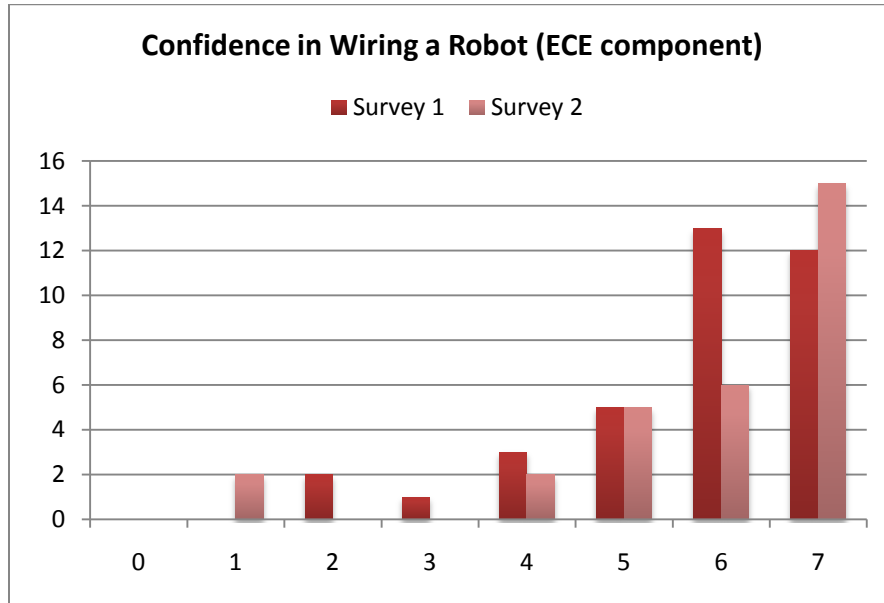
Figure 33

The next chart, found below, (Figure 34) shows the overall student responses when asked about their confidence in construction, programming, testing and wiring for the first survey. These responses show that most of the students felt very confident about completing all of the tasks.
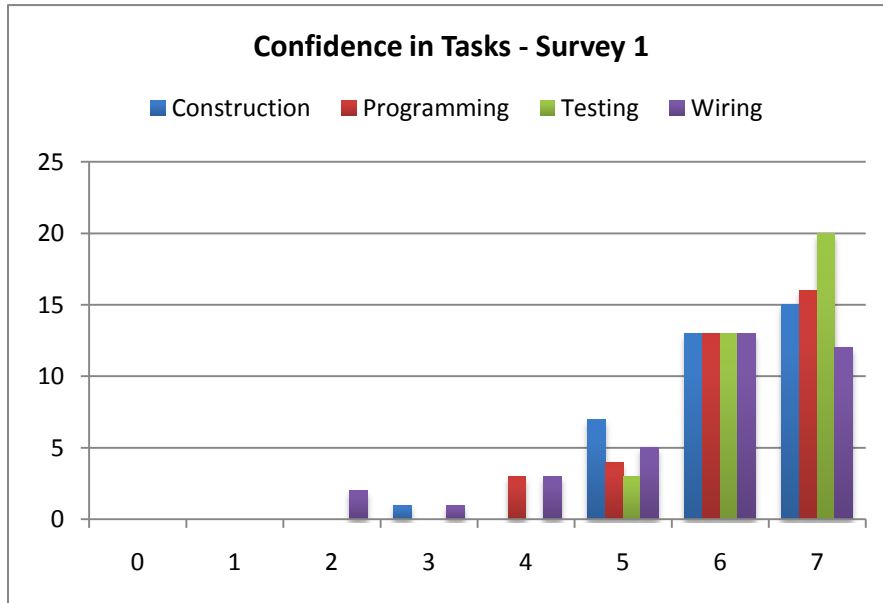
Figure 34

The next chart, found below, (Figure 35) shows the overall student responses when asked about their confidence in construction, programming, testing and wiring for the second survey. These responses show that most of the students felt even more confident about completing all of the tasks at the end of the term. From the survey results below, the general impression is that signal conditioning algorithms and creating an electrical system to convert battery energy into a signal to drive a DC motor are the two areas students were least confident about.
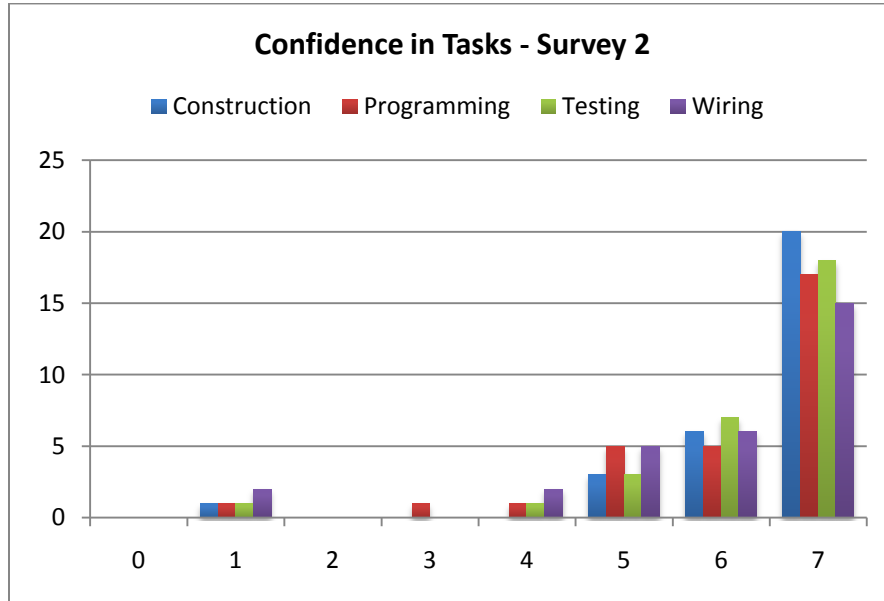
Figure 35

4.1.3 Unified Robotics III

The results of the Unified Robotics III surveys are shown in the charts below. In each chart, Survey 1 corresponds to the survey distributed at the beginning of the course, and Survey 2 to the survey distributed at the end of the course. The y-axis indicates the number of responses in each confidence level, and the x-axis indicates the confidence level response (with the exception of the first chart which displays question numbers on the x-axis). It is important to note that twenty-five students took Survey 1, while twenty-six students took Survey 2. Each chart is also accompanied by a brief description of what the chart shows and the important information that can be drawn from it.

The first chart shown below (Figure 36) is a graphical representation of the average responses from students in the Unified Robotics III course in C term 2010. The error bars displayed represent the standard deviation of the data, indicating that over 68% of responses were within the error bars. The data in this chart shows us that student confidence increased in all areas, shown by the higher level of the survey 2 average responses, and smaller error bars.
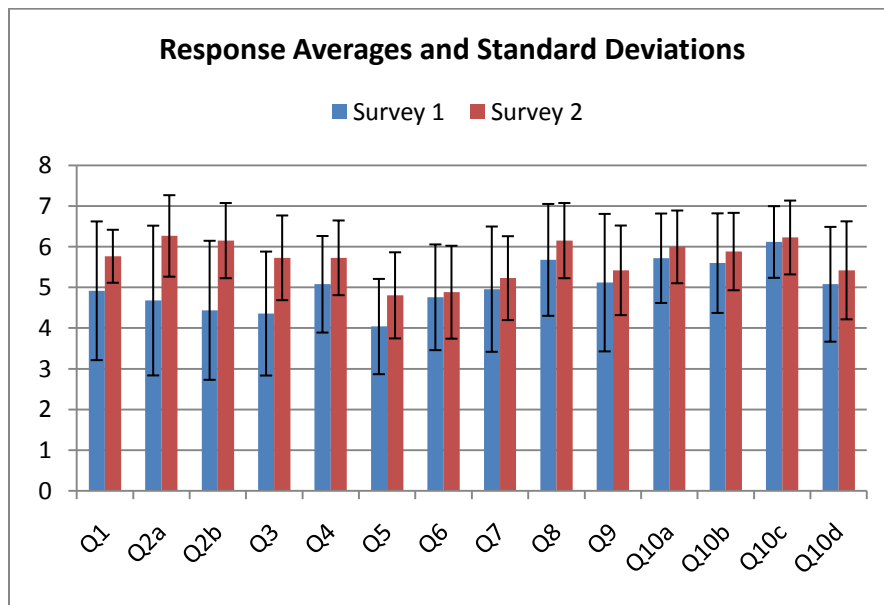
Figure 36

The table below contains the survey question topics corresponding to questions Q1 through Q10d in the Average Results chart shown above. Each question began with "How confidently do you feel that you could…," asking students to rate their confidence level on a scale from 1-7.

Table 5

| Question Number	Question
Q1	Demonstrate knowledge of different types of actuators.
Q2a	Analyze the position kinematics of a robot arm in 2D.
Q2b	Analyze the velocity kinematics of a robot arm in 2D.
Q3	Analyze the dynamics of a robot arm in 2D.
Q4	Analyze sensor signals to implement real-time control algorithms.
Q5	Demonstrate knowledge of error propagation in electrical systems.
Q6	Demonstrate knowledge of error propagation in mechanical systems.
Q7	Demonstrate knowledge of error propagation in computational systems.
Q8	Write moderately involved programs in C for a robot.
Q9	Create an electrical system to convert battery energy into a signal to drive a DC motor.
Q10a	Construct a mobile robotic system to perform a specified task.
Q10b	Program a mobile robotic system to perform a specified task.
Q10c	Test a mobile robotic system to perform a specified task.
Q10d	Wire a robot (ECE component).

The graph below (Figure 37) represents the students' responses to the survey question: How confidently do you feel that you could demonstrate knowledge of different types of actuators used in robotic systems? This question was created to investigate Course Objective 1 of the RBE 3001 syllabus which states: upon completion of this course, students will be able to demonstrate knowledge of different types of actuators used in robotic systems.

The general response from students at the beginning of the Unified Robotics III course shows that the majority of students felt moderately confident at a response of 5, with few students feeling less confident. In the second survey, we can see a clear improvement of confidence in their knowledge of different types of actuators. There are no responses under confidence level 5. This implies that this subject was conveyed well enough to make these students confident in the subject matter.

Figure 37

The graph below (Figure 38) represents the students' responses to the survey question: How confidently do you feel that you could analyze the position of a robot arm in 2D? This question was created to investigate Course Objective 2 of the RBE 3001 syllabus which states: upon completion of this course, students will be able to analyze the position and velocity kinematics of robot arm in 2D.

At the beginning of the course, the response from students was greatly varied. The most responses were of confidence level 6, but there were many responses of almost every other level as well. In the second survey, we can see a clear improvement in confidence in their ability to analyze the position of a robot arm. The majority of the responses were of 6 and 7 confidence and no responses fell below confidence level 4.

Figure 38

The graph below (Figure 39) represents the students' responses to the survey question: How confidently do you feel that you could analyze the velocity of a robot arm? This question was created to investigate Course Objective 2 of the RBE 3001 syllabus which states: upon completion of this course, students will be able to analyze the position and velocity kinematics of a robot arm in 2D.

At the beginning of the course, the responses from students were greatly varied. The most responses were of confidence level 6, but there were many responses of almost every other level as well. The answers seem to stretch across the board fairly evenly, which implies that some people feel confident with analyzing the velocity while others seem unconfident. In the second survey, we can see a clear improvement in confidence in their ability to analyze the velocity of a robot arm. The majority of the responses were of 6 and 7 confidence and no responses fell below confidence level 4. This implies that this subject was conveyed well enough to make these students confident in the subject matter.

Figure 39

The graph below (Figure 40) represents the students' responses to the survey question: How confidently do you feel that you could analyze the dynamics of a robot arm? This question was created to investigate Course Objective 3 of the RBE 3001 syllabus which states: upon completion of this course, students will be able to analyze the dynamics of a robot arm in 2D.

At the beginning of the course, the response from students was greatly varied. The most responses were of confidence level 4 and 5, but there were many responses of almost every other level as well. The answers seem to be focused in the middle confidence region, which implies that these students felt somewhat confident about analyzing the dynamics of a robot arm. In the second survey, we can see a clear improvement in confidence. The majority of the responses were of level 6 confidence and no responses fell below confidence level 4. This implies that this subject was conveyed well enough to make these students confident in the subject matter.
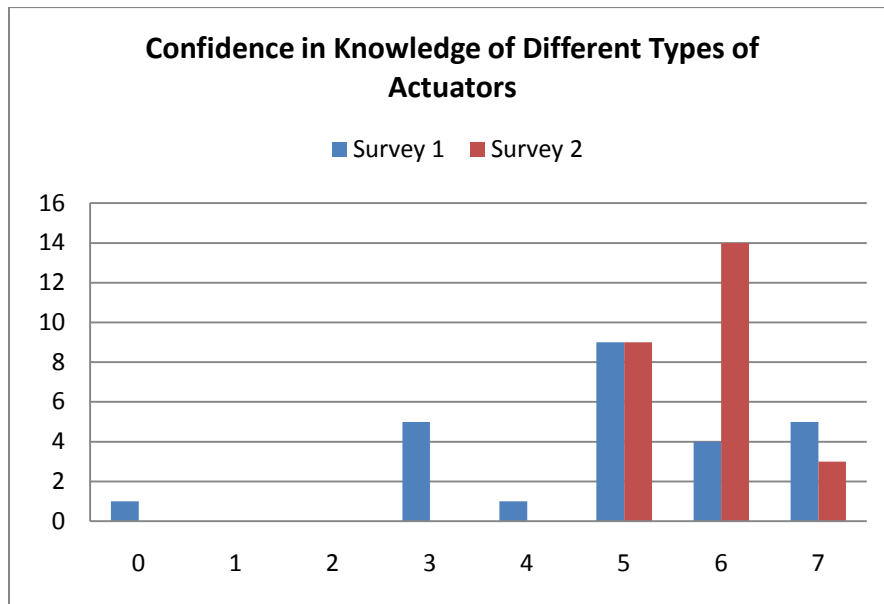

Figure 40

The graph below (Figure 41) represents the students' responses to the survey question: How confidently do you feel that you could analyze sensor signals in order to implement the real-time control algorithms? This question was created to investigate Course Objective 4 of the RBE 3001 syllabus which states: upon completion of this course, students will be able to analyze sensor signals to implement real-time control algorithms.

At the beginning of the course, the response from students was greatly varied. The most responses were of confidence level 4, 5 and 6. The answers seem to be focused towards very confident, which is good to see regarding this objective. In the second survey, we can see a clear improvement in confidence in their ability to analyze the sensor signals in order to implement real-time control algorithms. The majority of the responses were of level 6 confidence and only two responses fell below confidence level 5.

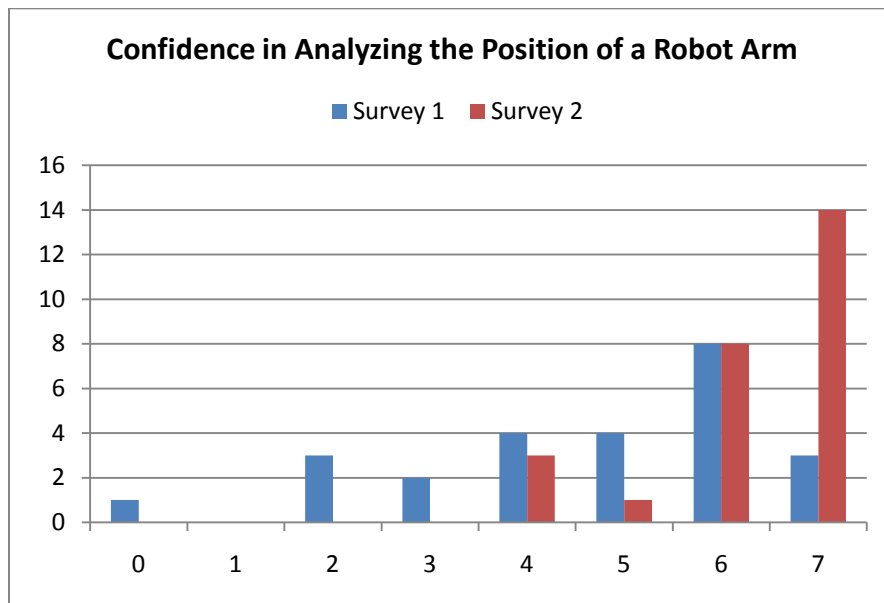**Figure 41**

The graph below (Figure 42) represents the students' responses to the survey question: How confidently do you feel that you could demonstrate knowledge of error propagation in electrical systems? This question was created to investigate Course Objective 5 of the RBE 3001 syllabus which states: upon completion of this course, students will be able to demonstrate knowledge of error propagation in electrical, mechanical and computational systems.

At the beginning of the course, the response from students was greatly varied. The most responses were of confidence level 3, 4 and 5. The answers seem to be focused towards somewhat confident, which implies that these students are not sure if they could do this now, but by the end of the course maybe they will. In the second survey, we cannot see as clear of an improvement in their knowledge of error propagation in electrical systems compared to the other objectives. The majority of the responses were of level 4 and 5 confidence and only two responses fell below confidence level 4. This implies that this subject was somewhat conveyed, but it seems that these students still do not feel as confident as they should in the subject matter.

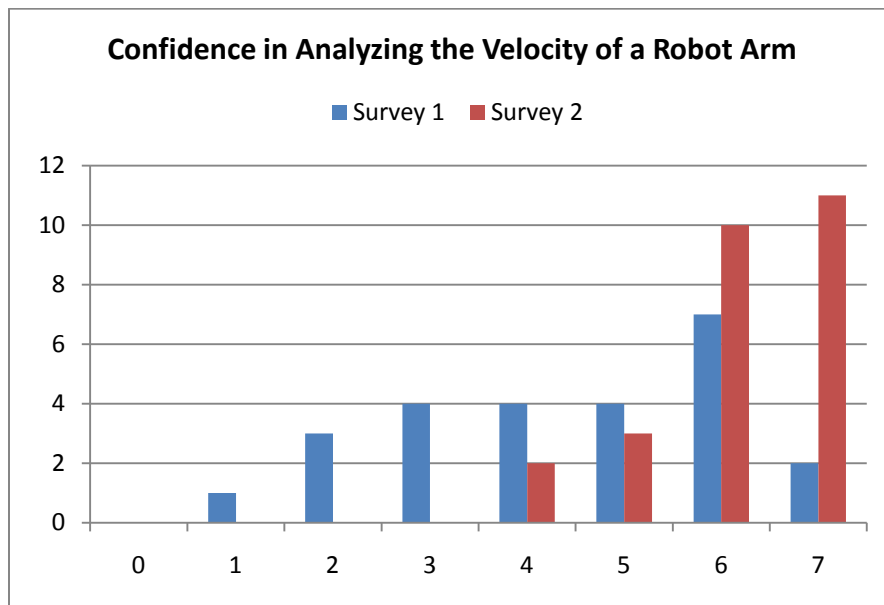**Figure 42**

The graph below (Figure 43) represents the students' responses to the survey question: How confidently do you feel that you could demonstrate knowledge of error propagation in mechanical systems? This question was created to investigate Course Objective 5 of the RBE 3001 syllabus which states: upon completion of this course, students will be able to demonstrate knowledge of error propagation in electrical, mechanical and computational systems.

At the beginning of the course, the response from students was greatly varied. The most responses were of confidence level 4, 5 and 6. The answers seem to be focused towards a high confidence level, which implies that these students seem to understand the objective very well now, but that may change by the end of the course. In the second survey, we cannot see as clear of an improvement in their knowledge of error propagation in mechanical systems compared to the other objectives. The majority of the responses were of level 4 and 5 confidence and only three responses fell below confidence level 4. This implies that this subject was somewhat conveyed, but it seems that these students still do not feel as confident as they should in the subject matter.

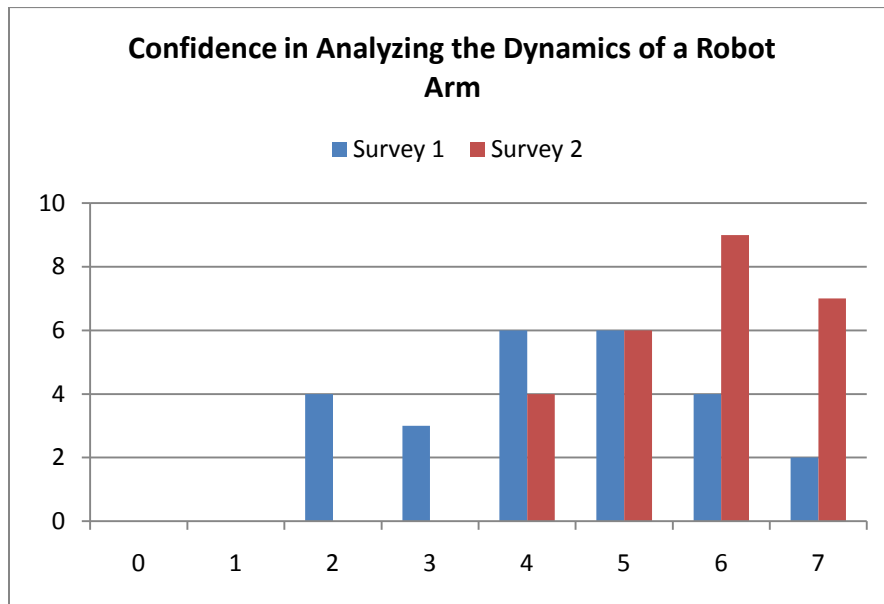**Figure 43**

The graph below (Figure 44) represents the students' responses to the survey question: How confidently do you feel that you could demonstrate knowledge of error propagation in computational systems? This question was created to investigate Course Objective 5 of the RBE 3001 syllabus which states: upon completion of this course, students will be able to demonstrate knowledge of error propagation in electrical, mechanical and computational systems.

At the beginning of the course, the response from students was greatly varied. The responses seem to be ranging in confidence, which implies that some of these students feel confident while others do not. In the second survey, we cannot see as clear of an improvement in their knowledge of error propagation in computational systems compared to the other objectives. The majority of the responses were of level 6 confidence and only one response fell below confidence level 4. This implies that this subject was somewhat conveyed, but it seems that these students still do not feel as confident as they should in the subject matter.
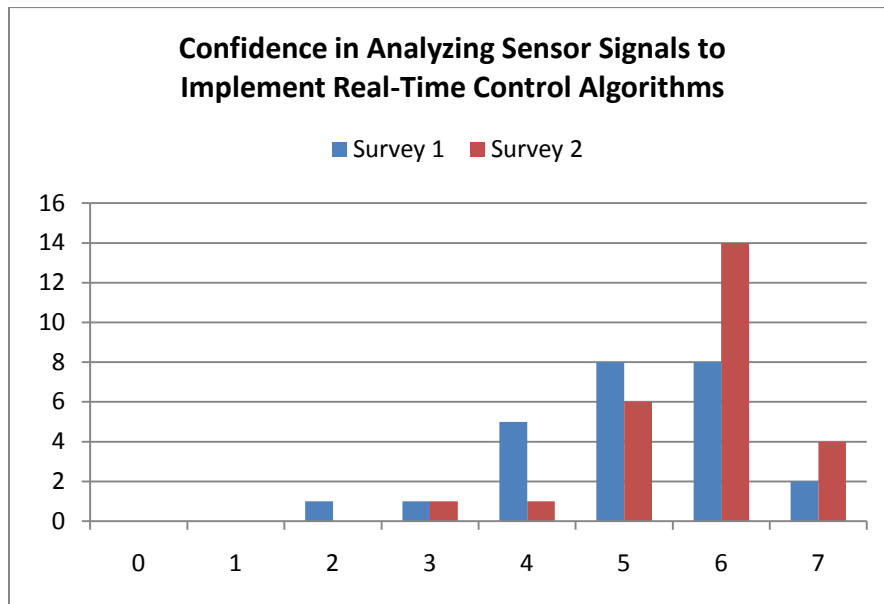

Figure 44

The graph below (Figure 45) represents the students' responses to the survey question: How confidently do you feel that you could write moderately involved programs in C for a robot? This question was created to investigate Course Objective 6 of the RBE 3001 syllabus which states: upon completion of this course, students will be able to write moderately involved programs in C to perform a specified task with a robotic system in real-time.

At the beginning of the course, the response from students was greatly varied. The most responses were of confidence level 6 and 7. The answers seem to be focused towards very confident, which implies that these students understand how to write programs in C and how it incorporates into their major. In the second survey, we can see a clear improvement in confidence in their ability to write moderately involved programs in C for a robot. The majority of the responses were of level 6 and 7 confidence and no responses fell below confidence level 4. This implies that this subject was conveyed well enough to make these students feel confident in their knowledge of the subject matter.

Figure 45

The graph below (Figure 46) represents the students' responses to the survey question: How confidently do you feel that you could create an electrical system to convert battery energy into a signal to drive a DC motor? This question was created to investigate Course Objective 7 of the RBE 3001 syllabus which states: upon completion of this course, students will be able to construct, program, and test the operation of a robotic system to perform a specified task.

At the beginning of the course, the response from students was greatly varied. The most responses were of confidence level 6 and 7, but there also seems to be some unconfident answers as well. The answers seem to be very confident and it allows us to realize that these students understand how to complete this objective enough. In the second survey, we cannot see as clear of an improvement in their knowledge of creating an electrical system to convert battery energy into a signal to drive a DC motor. The majority of the responses were of level 6 confidence and only one response fell below confidence level 4. This implies that this subject was somewhat conveyed, but it seems that these students still do not feel as confident as they should in the subject matter.
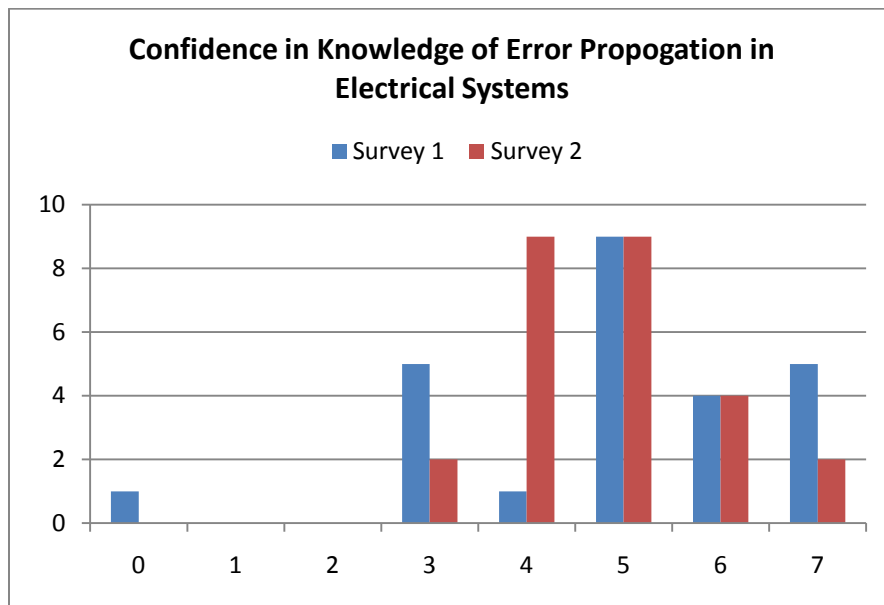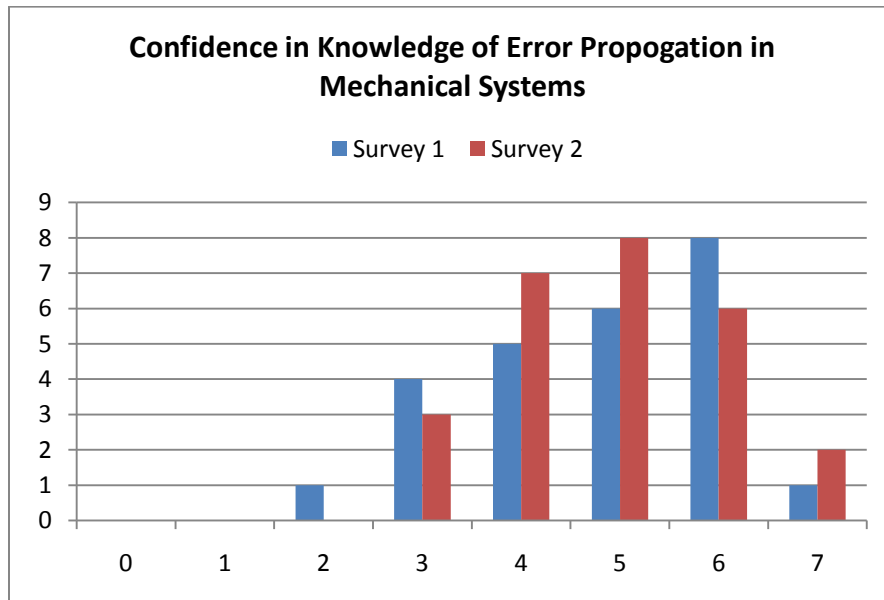

Figure 46

The graph below (Figure 47) represents the students' responses to the survey question: How confidently do you feel that you could construct a mobile robotic system to perform a specified task? This question was created to investigate Course Objective 7 of the RBE 3001 syllabus which states: upon completion of this course, students will be able to construct, program, and test the operation of a robotic system to perform a specified task.

At the beginning of the course, the response from students was greatly varied. The most responses were of confidence level 5, 6 and 7. The answers seem to be very confident and it allows us to realize that these students feel they understand how to complete this objective very well. In the second survey, we cannot see as clear of an improvement in their ability to construct a mobile robotic system to perform a specified task. The majority of the responses were of level 6 and 7 confidence, which is very similar to the results of the first survey. This implies that these students felt confident in their knowledge of the subject matter before and after the course was over.
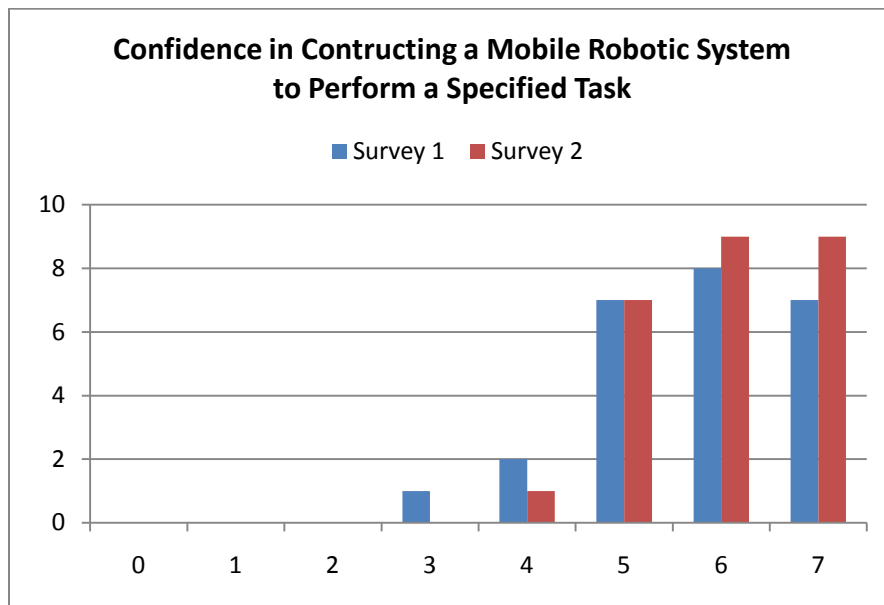
Figure 47

The graph below (Figure 48) represents the students' responses to the survey question: How confidently do you feel that you could program a mobile robotic system to perform a specified task? This question was created to investigate Course Objective 7 of the RBE 3001 syllabus which states: upon completion of this course, students will be able to construct, program, and test the operation of a robotic system to perform a specified task.

At the beginning of the course, the response from students was greatly varied. The most responses were of confidence level 5, 6 and 7. The answers below seem to be very confident and it allows us to realize that these students understand how to complete this objective very well. In the second survey, we cannot see as clear of an improvement in their ability to program a mobile robotic system to perform a specified task. The majority of the responses were of level 6 and 7 confidence, which is very similar to the results of the first survey. This implies that these students felt confident in their knowledge of the subject matter before and after the course was over.
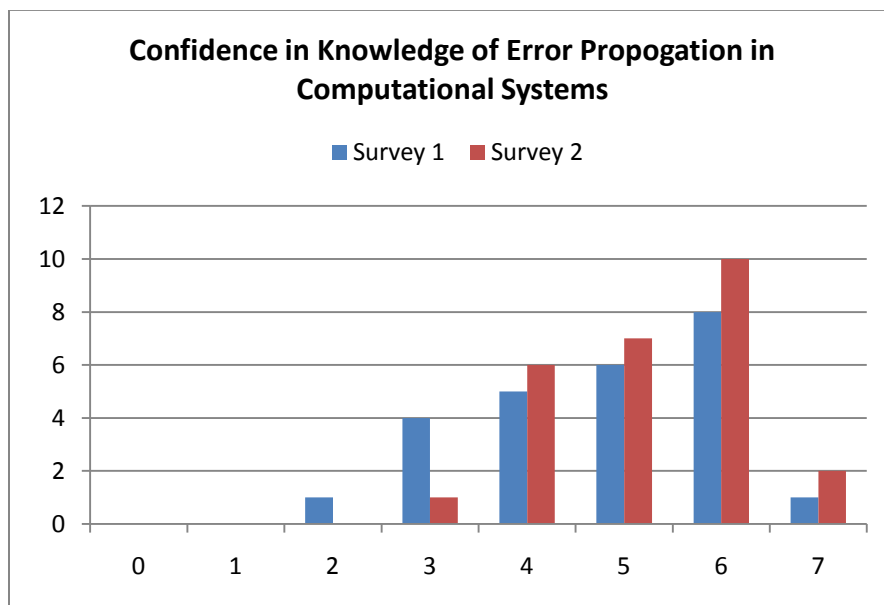

Figure 48

The graph below (Figure 49) represents the students' responses to the survey question: How confidently do you feel that you could test the operation of a mobile robotic system to perform a specified task? This question was created to investigate Course Objective 7 of the RBE 3001 syllabus which states: upon completion of this course, students will be able to construct, program, and test the operation of a robotic system to perform a specified task.

At the beginning of the course, the response from students was mainly confident. The most responses were of confidence level 6 and 7. The answers seem to be very confident and it allows us to realize that these students understand how to complete this objective very well. In the second survey, we can see a clear improvement in confidence in their ability to test the operation of a mobile robotic system to perform a specified task. The majority of the responses were of level 6 and 7 confidence and only one response fell below confidence level 4. This implies that this subject was conveyed well enough to make these students confident in the subject matter.
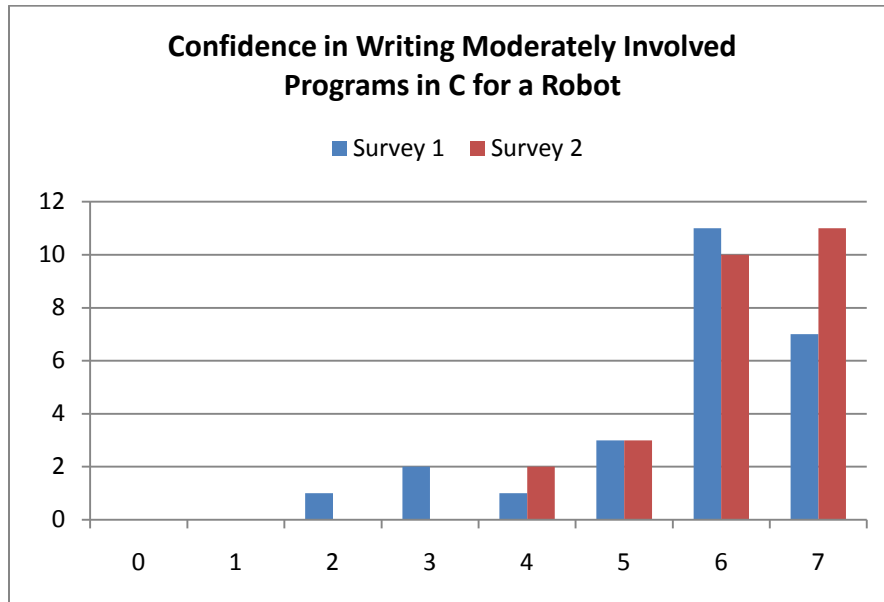

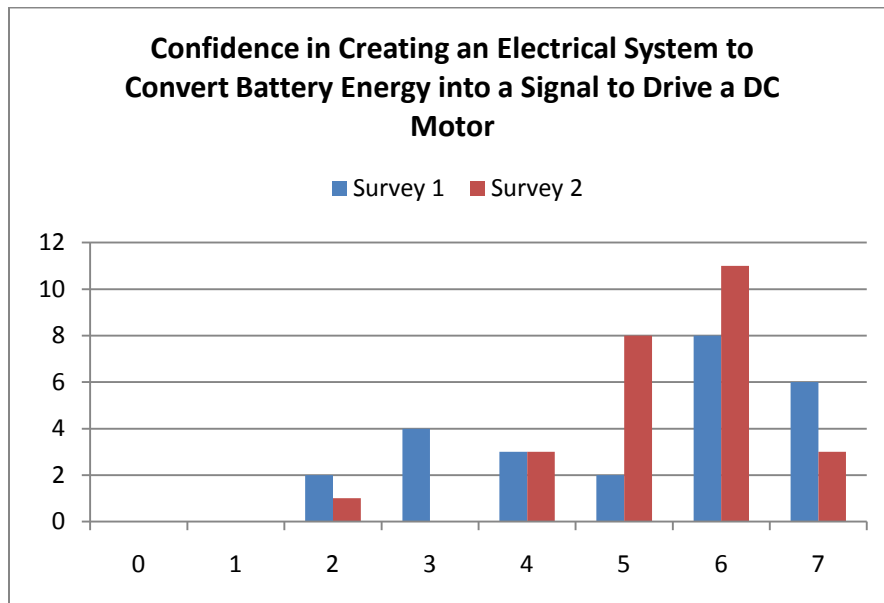**Figure 49**

The graph below (Figure 50) represents the students' responses to the survey question: How confidently do you feel that you could wire a robot? This question was created to investigate Course Objective 7 of the RBE 3001 syllabus which states: upon completion of this course, students will be able to construct, program, and test the operation of a robotic system to perform a specified task.

At the beginning of the course, the response from students was greatly varied. The most responses were of confidence level 5. The answers emphasize that some students feel confident about this objective while others do not. Therefore, this would be a great objective to improve upon as the course goes on. In the second survey, we cannot see as clear of an improvement in their ability to wire a robot. The majority of the responses were of level 4, 5, 6 and 7 confidences, which is very similar to the results of the first survey.
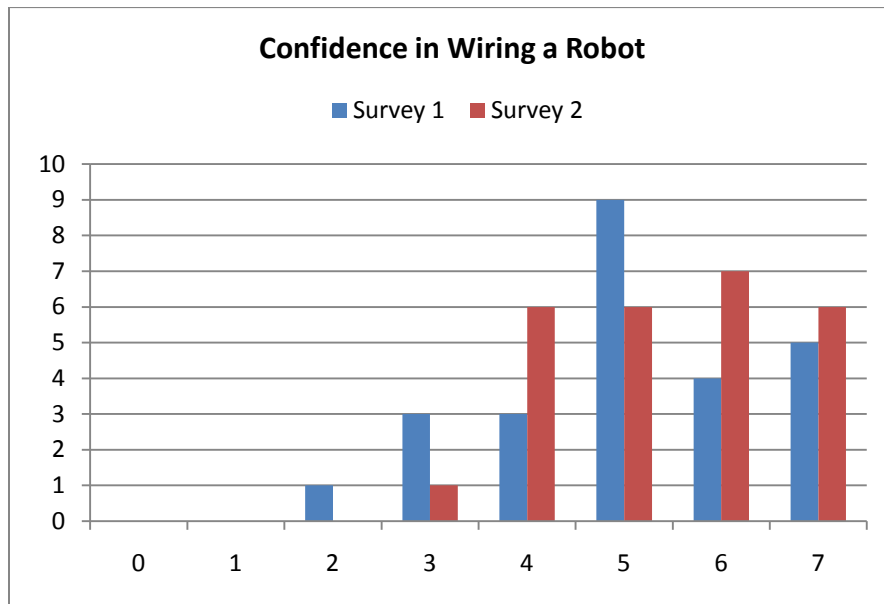
Figure 50

The graph below (Figure 51) represents the overall answers of Survey 1 for constructing, programming, testing and wiring a robot. The only subjects that seem to be an issue are wiring and programming a robot. These were the expected subjects that we believed would need the most work because these typically prove to be the most difficult. These students seem very confident in testing and constructing a robot.
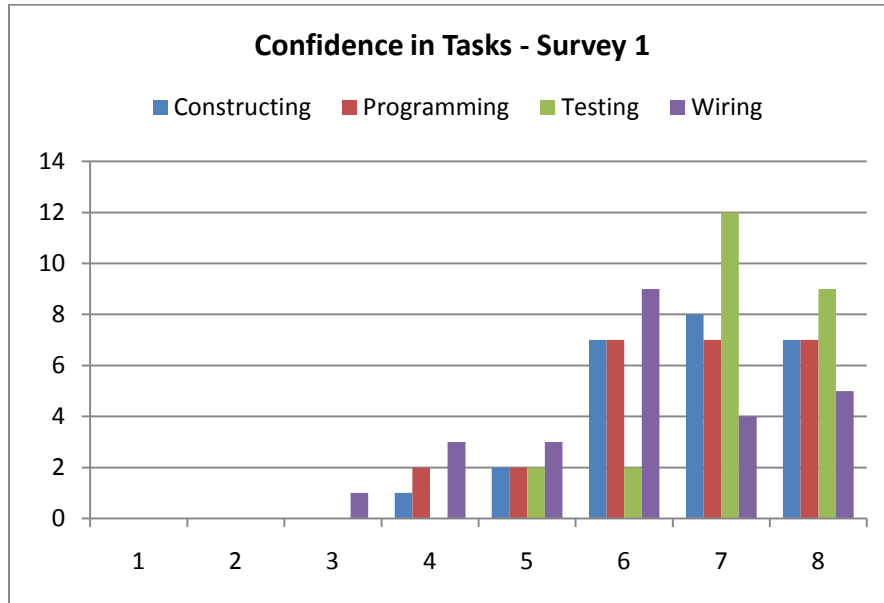
Figure 51

The graph below (Figure 52) represents the overall answers of Survey 2 for constructing, programming, testing and wiring a robot. All the subjects seemed to have balanced out in confidence, which is the point of the RBE program. These students felt confident in all aspects of the RBE 3001 course and have improved since the beginning of the course.
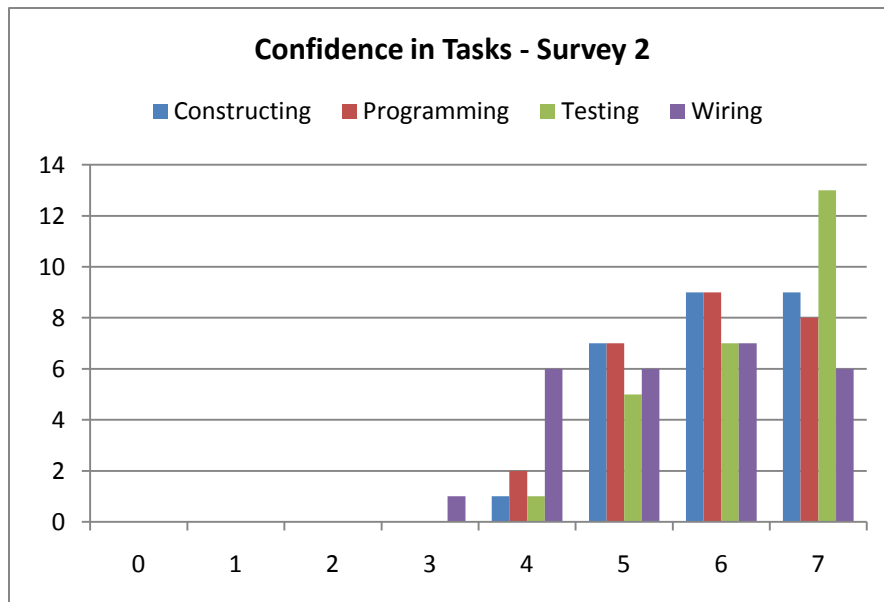
Figure 52

4.1.4 Unified Robotics IV

In B term of 2009 we also surveyed students that completed the Unified Robotics series in the spring of 2009 by taking the Unified Robotics IV course. Twenty of these students completed our online survey, the results of which are depicted in the charts below. Each chart is accompanied by a brief description of valuable information we can gather from it.

The graph below (Figure 53), titled courses taken, is the result of the survey question asking students which courses they had completed. From this chart, we see that of the twenty students who completed the survey, only one did not take the RBE 1001: Introduction to Robotics Engineering course.

Courses Taken

| Course	Value
RBE 3002	20
RBE 3001	20
RBE 2002	20
RBE 2001	20
RBE 1001	19

(x-axis: 18.4, 18.6, 18.8, 19, 19.2, 19.4, 19.6, 19.8, 20, 20.2)
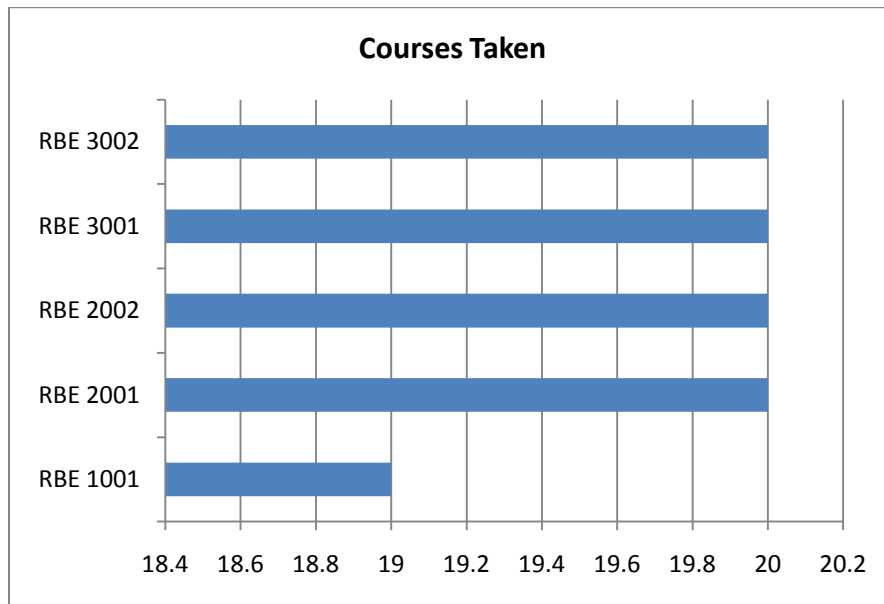
Figure 53

The graph below (54) represents the students' responses to the survey question: How confidently do you feel that you could compute the mobile kinematics of a robot? There were fourteen responses that fell in the 6 or 7 confidence level, with the rest of the responses spread out among the other levels. Four students ranked themselves at neutral or lower.
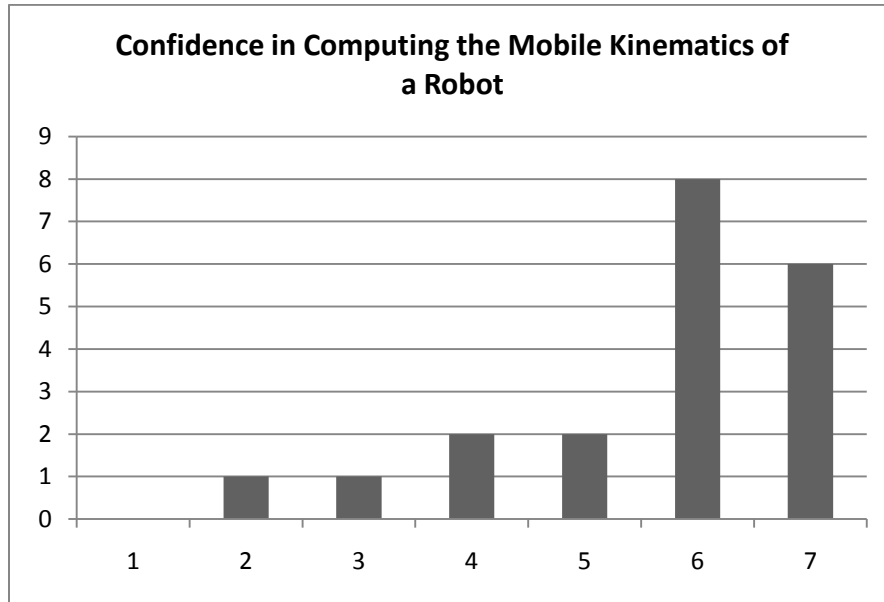
Figure 54

The graph below (Figure 5055) represents the students' responses to the survey question: How confidently do you feel that you could develop a model for mobile robotic platform dynamics? The responses were relatively high, ten of which fell in the 6 or 7 confidence level. Five students ranked themselves with a 5, while five (a quarter of the responses) put themselves at neutral or lower.
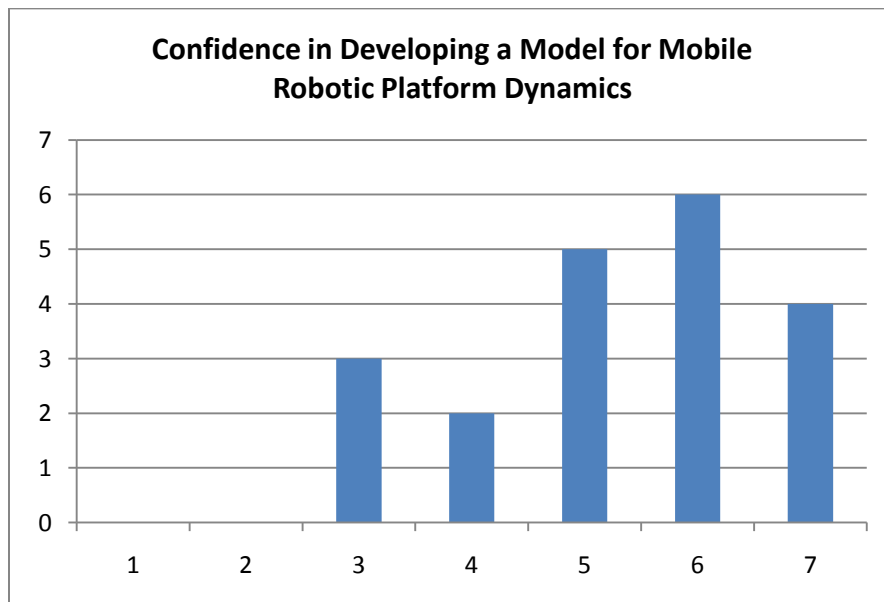
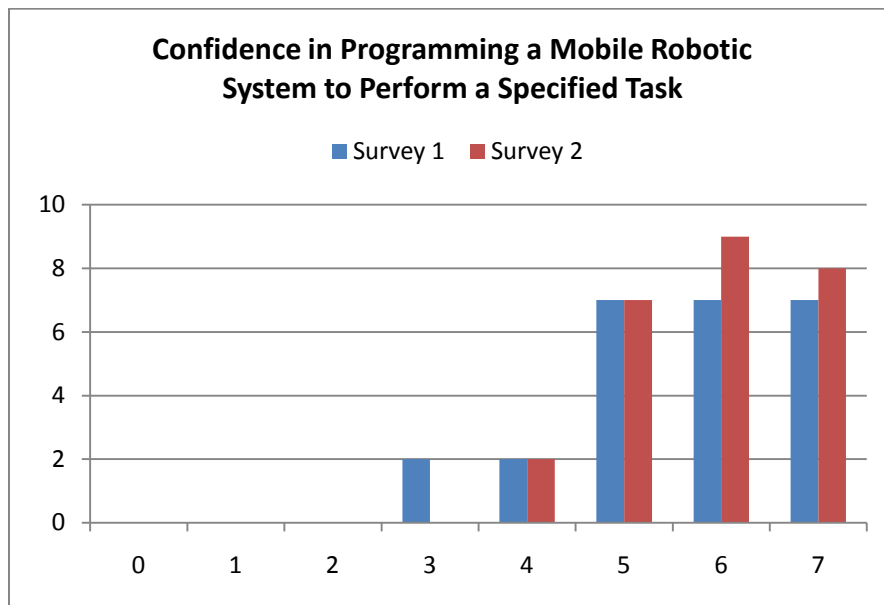**Figure 55**

The graph below (Figure 56) represents the students' responses to the survey question: How confidently do you feel that you could implement navigation algorithms based on sensor combinations and environmental representations? All of the responses fell in the 5-7 confidence level range. Eleven of the twenty students ranked themselves at the highest level.
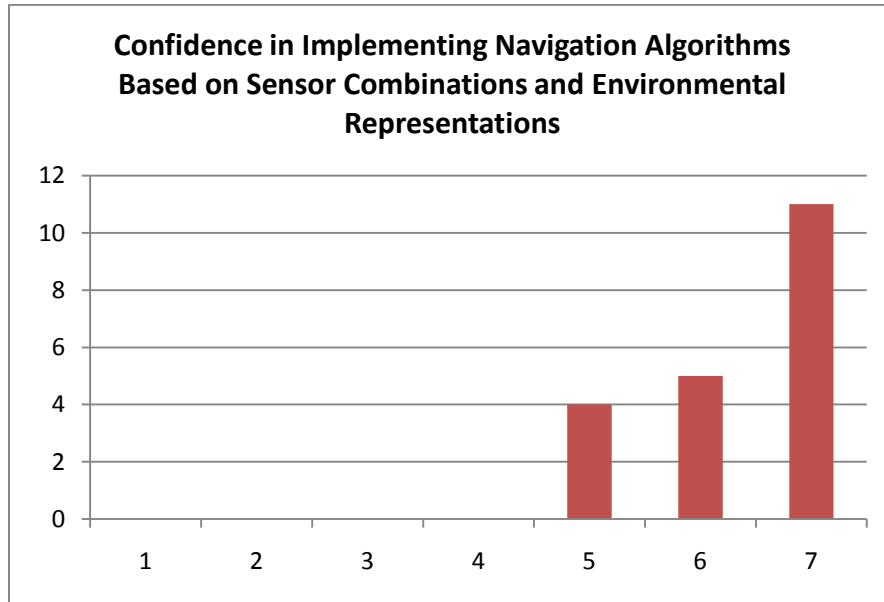
Figure 56

The graph below (Figure 57) represents the students' responses to the survey question: How confidently do you feel that you could write moderately involved C++ programs for a robot? Only three students put themselves at neutral or lower. Half of them ranked their confidence in performing this task as high as it could be.
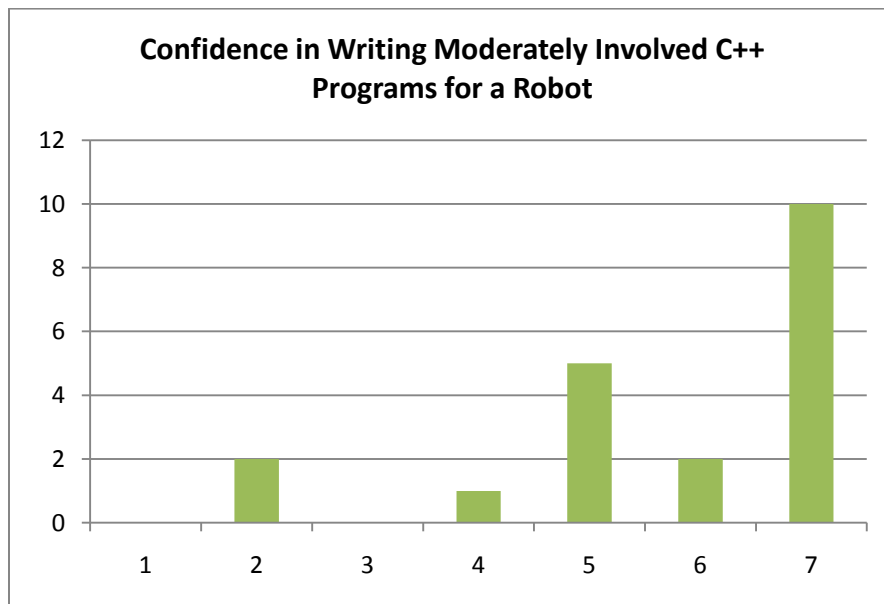
Figure 57

The graph below (Figure 508) represents the students' responses to the survey question: How confidently do you feel that you could create an electrical system to convert battery energy into a signal to drive a DC motor? The majority of the responses fall in the 5-7 range, with only three in the neutral or lower range.
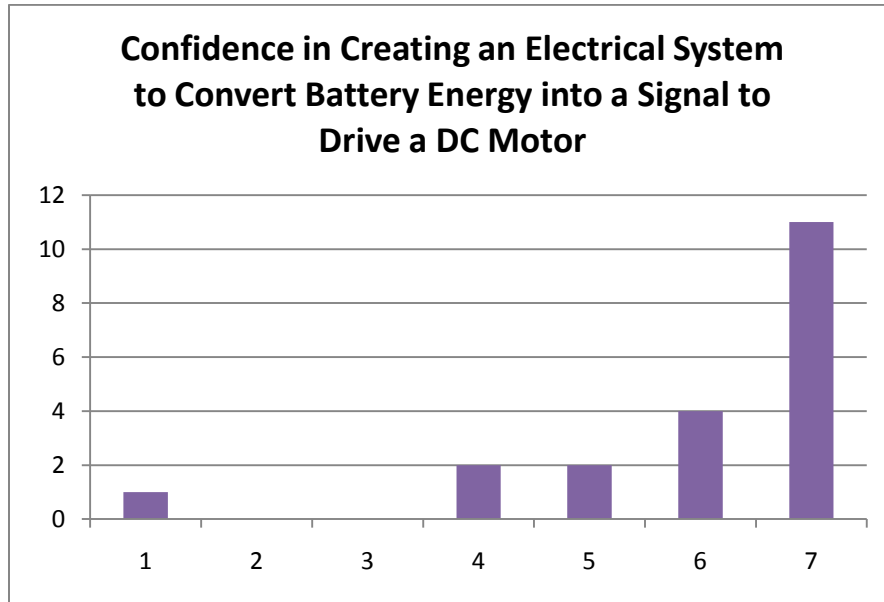
Figure 58

The graph below (Figure 509) represents the students' responses to the survey question: How confidently do you feel that you could construct a mobile robotic system to perform a specified task? The majority of the responses fall in the 5-7 range. The confidence levels of 5 and 6 each had three people, with level 7 collecting twelve. Only two students responded with 4 or lower.
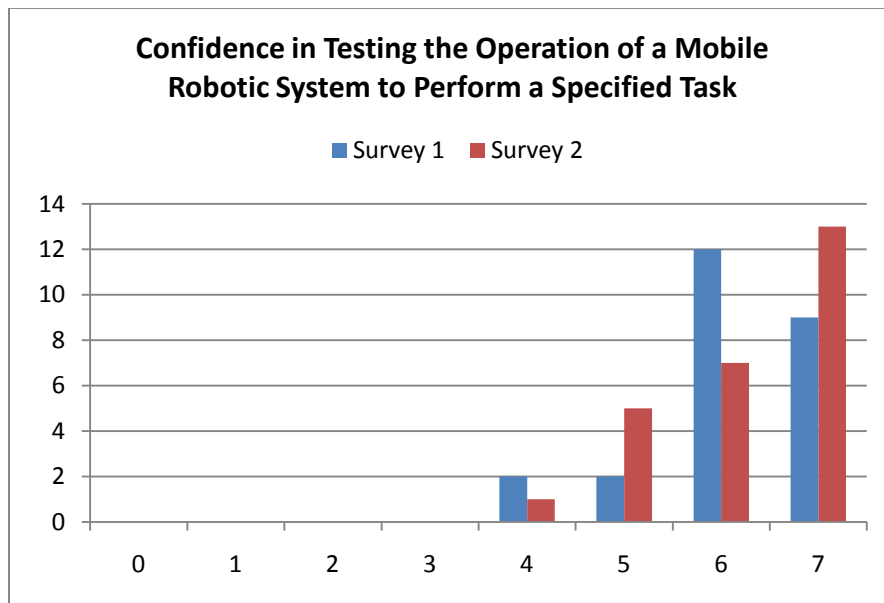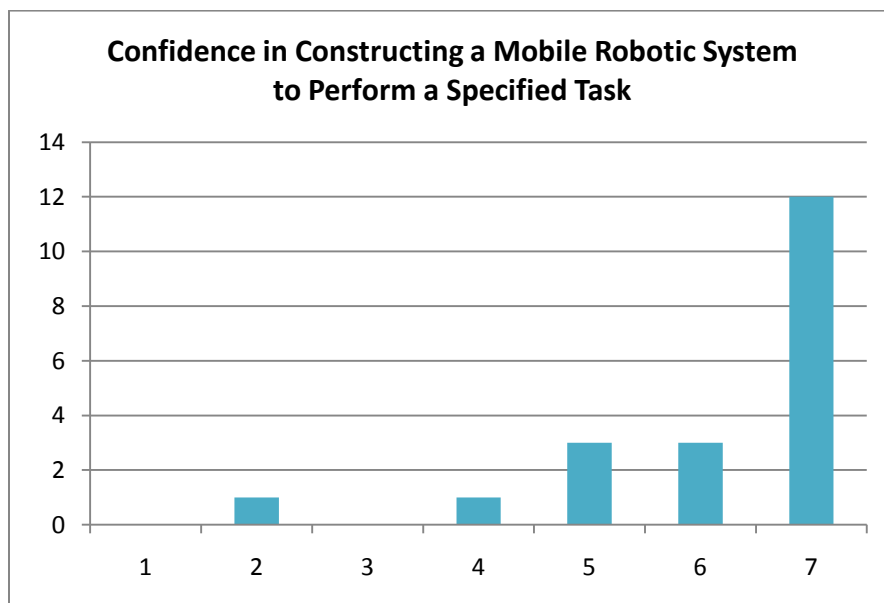

Figure 59

The graph below (Figure 50) represents the students' responses to the survey question: How confidently do you feel that you could program a mobile robotic system to perform a specified task? The vast majority of students responded with the most confidence possible. Only five students responded with a lower confidence indication, and the lowest response was of 5. This shows us that overall, students who have completed the unified robotics series are quite confident in programming mobile robotics systems to perform a specified task.

Confidence in Programming a Mobile Robotic System to Perform a Specified Task
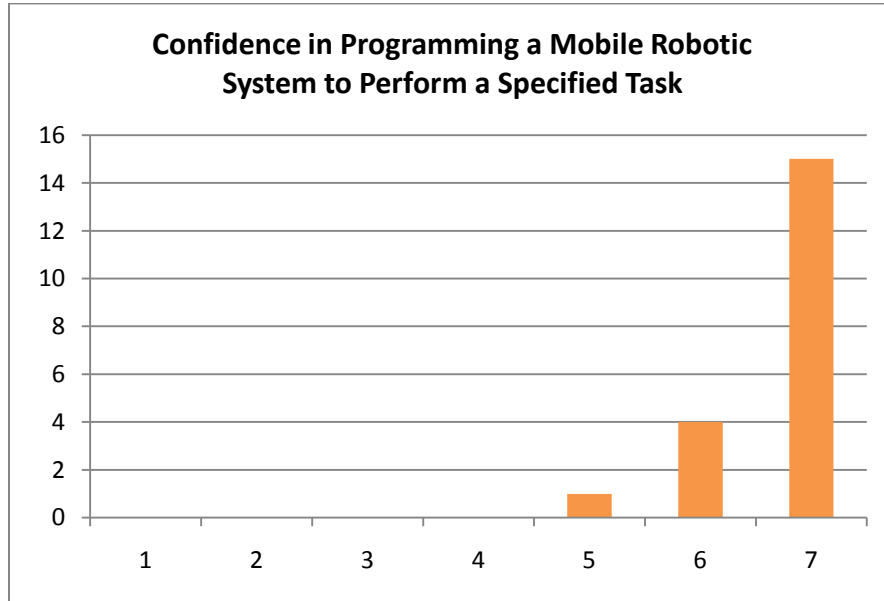
Figure 60

The graph below (Figure 5061) represents the students' responses to the survey question: How confidently do you feel that you could test the operation of a mobile robotic system? The responses indicate an even greater confidence level than on other topics from the students. Only three students indicated a confidence less than 7, with responses of 5 or 6. This shows overwhelming confidence in testing robots from students who have completed the robotics curriculum.
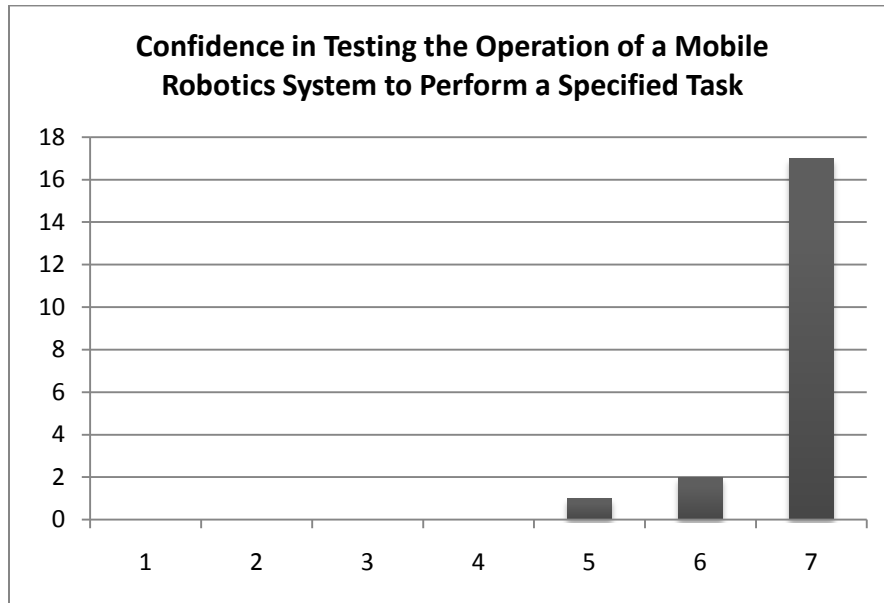
Figure 61

The graph below (Figure 5062) represents the students' responses to the survey question: How confidently do you feel that you could wire a robot (ECE component)? The responses were slightly more spread out than the previous few charts, but only one student responded as low as 4, and the remaining students responded with a 5, 6 or 7. This still indicates a quite good amount of confidence in wiring a robot from students who have completed the unified robotics courses.
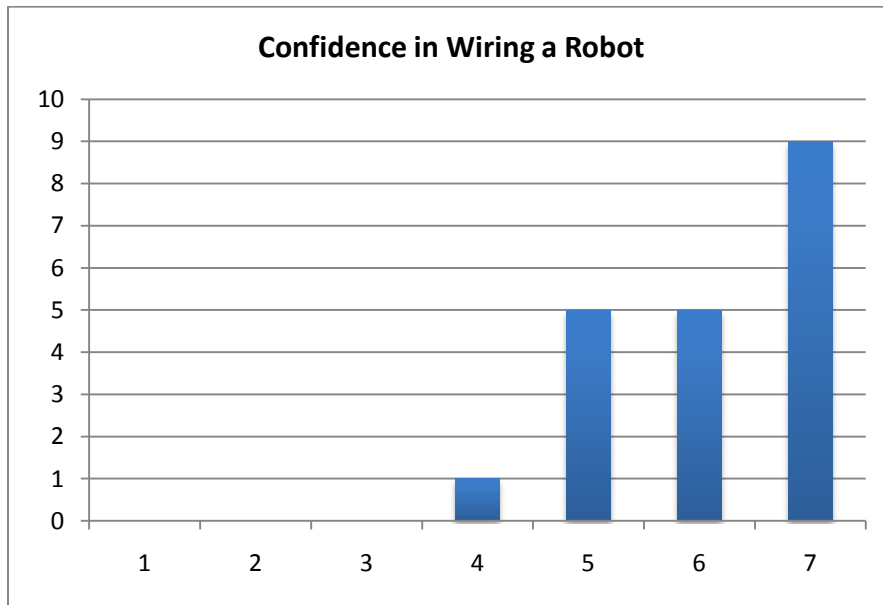
Figure 62

The final graph below (Figure 63) is a compilation of the previous four graphs. This graph allows us to compare student confidence across the four general focus areas in the robotics program. This graph indicates that in general, students are most confident in testing and programming, and not quite as confident in construction or wiring. The overall confidence in each, however, is quite good. Only one response was below a 4 in any of the four categories.
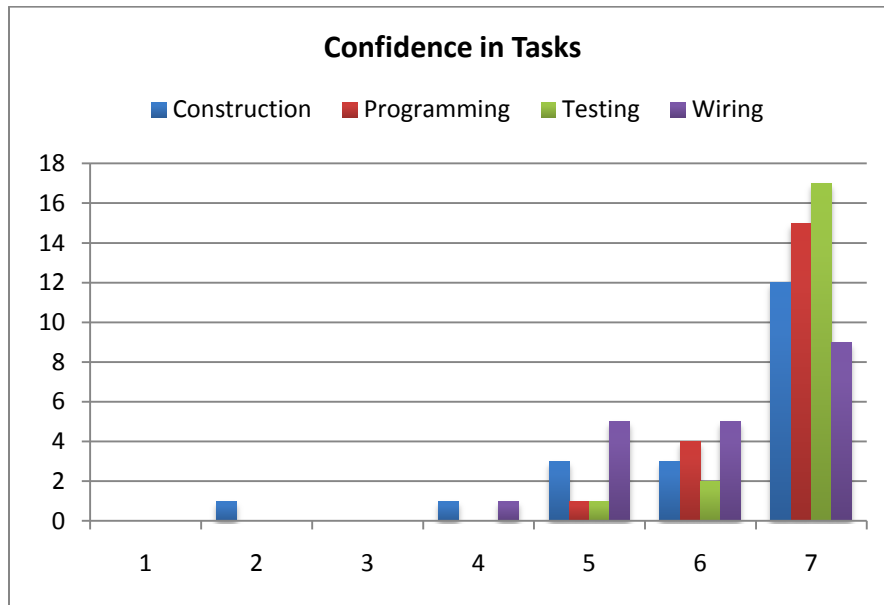
Figure 63

4.2   RBE Self Study

One of the most important parts of our project was creating Section 2, 3 and 4 of the RBE self study. We completed these parts because Professor Looft and Professor Schachterle both emphasized that we needed to extend our project beyond the initial conditions and that we would be able to assist in starting these sections. Within these sections, we used the ECE self study report that was sent to ABET as our template so that we could determine what needed to go in its proper place within each section.

4.2.1   Section 2

CRITERION 2. PROGRAM EDUCATIONAL OBJECTIVES
This section provides the Mission and Educational Objectives of the Robotics Engineering Program and their consistency with those of WPI. The objectives characterize our graduates a few years after graduation. Also described are the processes we have in place to periodically evaluate and, if necessary, revise the objectives of the program to meet the changing needs of the robotics engineering field.

Mission Statement
The mission of the institution is provided below. The mission is printed in the Undergraduate Catalog, and is available at: http://www.wpi.edu/Pubs/Catalogs/Ugrad/Current/mission.html

WPI educates talented men and women in engineering, science, management, and humanities in preparation for careers of professional practice, civic contribution, and leadership, facilitated by active lifelong learning. This educational process is true to the founders' directive to create, to discover, and to convey knowledge at the frontiers of academic inquiry for the betterment of society. Knowledge is created and discovered in the scholarly activities of faculty and students ranging across educational methodology, professional practice, and basic research. Knowledge is conveyed through scholarly publication and instruction. Adopted by the Board of Trustees, May 22, 1987

The goal of WPI is provided below. The goal is printed in the Undergraduate Catalog, and is available at: http://www.wpi.edu/Pubs/Catalogs/Ugrad/Current/goal.html

WPI was founded in 1865 to create and convey the latest science and engineering knowledge in ways that would be most useful to the society from which its students came. Since that time, the disciplines of human inquiry have expanded extraordinarily, as have WPI's constituencies. The WPI curriculum, accordingly, has been reshaped numerous times, but it has remained true to its original mission of fusing academic inquiry with social needs, of blending abstraction with immediacy, of linking new knowledge to applications. The goals of the undergraduate program are to lead students to develop an excellent grasp of fundamental concepts in their principal areas of study; to lay a foundation for life-long renewal of knowledge; to gain a mature understanding of themselves; and, most importantly, to form a deep appreciation of the interrelationships among basic knowledge, technological advance, and human need. These principles are today manifest in the WPI Plan, a unique, project-oriented program which emphasizes intensive learning experiences and direct application of knowledge. WPI remains committed to continued educational improvement and innovation.

The goals of WPI's programs of graduate instruction and research are to create and convey knowledge at the frontiers of academic inquiry. These endeavors are founded on the principle that vigorously pursued and rigorously assessed scholarship is the lifeblood of the institution. High quality graduate instruction conveys the arts of scholarship to new generations, and it assists working professionals in maintaining currency in a world where knowledge becomes obsolete with ever-increasing rapidity. A WPI education encompasses continuous striving for excellence coupled with an examination of the contexts of learning so that knowledge is won not only for its own sake but also for the sake of the human community of which the people of WPI are part. Endorsed by the WPI Faculty on March 5, 1987, and by the Board of Trustees on October 16, 1987.

Robotics Engineering Program Educational Objectives
The Robotics Engineering Educational Objectives are published in the university catalog, and are available on-line at: http://www.wpi.edu/academics/Majors/RBE/academics.html

The Educational Objectives for the Bachelor Degree in Robotics Engineering are that all graduates:

1. Have a basic understanding of the fundamentals of Computer Science, Electrical and Computer Engineering, Mechanical Engineering, and Systems Engineering.
2. Apply these abstract concepts and practical skills to design and construct robots and robotic systems for diverse applications.
3. Have the imagination to see how robotics can be used to improve society and the entrepreneurial background and spirit to make their ideas become reality.
4. Demonstrate the ethical behavior and standards expected of responsible professionals functioning in a diverse society.

As we looked over these objectives, we believed that they were not a sufficient view of what WPI students should know after they have completed their bachelor's degree. We decided that we would create a new set of RBE objectives that would better suffice the knowledge that a WPI student should possess. We completed this task because we believed that these objectives needed to be refreshed to better encompass the three majors that made up the RBE major. The new objectives are listed below, but the process that we followed is shown in Section 7.1 Appendix A.

The proposed Educational Objectives for the Bachelor Degree in Robotics Engineering are that all graduates:

1. Should pursue lifelong learning, and prepare for immediate professional practice and continual development
2. Should be able to apply the fundamental principles of mathematics, science, and engineering to real life problems in the field of robotics engineering
3. Should have the ability to work effectively on a team
4. Should be able to relate the effects of his or her technological work to humankind in a positive way, and understand the impact it will have on society
5. Should possess leadership abilities, as well as technical and nontechnical communication skills

These objectives were designed by taking the educational objectives of the three majors that encompass the RBE major and finding correlations between them.

Consistency of the RBE Program Educational Objectives with the Mission of the Institution

The RBE Educational Objectives are consistent with the mission and goal statements of WPI. The RBE Program Educational Objectives reflect the expected accomplishments of our graduates a few years after graduation. By educating students in the fundamentals of mathematics, science and robotics engineering, we are preparing them for careers in professional practice. Preparation for careers is also accomplished by graduating students with interpersonal and communication skills. By developing their understanding of ethical responsibility and their appreciation of the interrelationships between technology and society, we are preparing them for civic duty. We embrace the ideal of lifelong learning within the RBE program.

Further, our Educational Objectives are consistent with the ABET criteria for Accrediting Engineering Programs.

Process for Determination of RBE Program Educational Objectives

The RBE educational objectives were designed by combining the educational objectives of the three encompassing majors of the RBE major and mapping the correlations between them. We analyzed the three sets of objectives on one sheet of paper and color coded the overlapping statements from each major. From there, we created objectives that seemed to combine the basic topics of the three majors. This mapping can be found in Appendix A.

Program Constituencies

Primary responsibility for the quality of the Robotics Engineering Program and the quality of the graduating students rests with the Associated Faculty. The Faculty established objectives and outcomes, periodically review the program needs, and deliver the curriculum designed to accomplish the objectives and outcomes. The program also benefits from the input of multiple constituencies, which are:

1. Current and Prospective RBE Students,
2. RBE Faculty,
3. RBE Alumni,
4. RBE Advisory Board, and
5. Employers of RBE Graduates (a future resource).

The primary constituents are the RBE students, both current students and future students for whom we establish and improve our program. Our institution and curriculum clearly seeks to serve a particular sub-group of potential students, those who are both talented in mathematics and engineering and those who are capable of benefiting from our educational approach. Given this set of prospective students, we aim to determine and meet their needs.

The faculty plays a dual role as a constituent, but more importantly, as the group responsible for program determination and execution. In it important to note that the faculty's first goal is to determine the needs of various constituencies, rather than their desires. This is particularly

significant for prospective, and even current, students. What a person needs at a given point in time may be very different from what he or she wants. The process of education, at least through the B.S. level, addresses the maturation of students very broadly. While an employer may be able to state his/her needs very clearly, a student may not be in such a position. This does not imply that we should not listen to our students, but rather than we must interpret what they are saying in terms of our mission as an institution.

Each of our constituents has a distinct, and different, involvement in the RBE program. Constituent needs also exist on several different times scales. For example, an aspect of an employer's needs in RBE is student familiarity with the current state of technology, but this must be balanced with an education in fundamentals that will enable our graduates to adapt to the next technological breakthrough. Secondary constituents could be identified and listed, ranging from the companies who sponsor students' projects, to the parents of our students, to society at large. However, the indicated list is felt to be sufficiently complete. Where appropriate, these others groups may be involved, but our desire is to restrict our constituent list to a manageable number.

Students

Two groups of students are of importance – prospective students and current RBE students. With regard to prospective students, the RBE program does not independently contact prospective students in a broad fashion.

WPI as an institution devotes considerable attention to surveys and focus groups with prospective students and their parents. Such studies provide a profile of the expectations and desires of our applicant pool; however, as interesting and useful as this information is when provided to the individual departments and programs, it is not possible to directly translate it into a curriculum. Input from current RBE students is solicited in several ways. Formally, feedback is gathered through course evaluations, the campus-wide EBI survey, and the RBE senior exit survey. Course evaluations provide both quantitative and qualitative data on individual courses and faculty members. The EBI survey allows the institute to compare the response from WPI students to results from students at other institutions. The senior exit survey is tailored to RBE students and a copy of the survey is provided in Appendix E. As the first student graduated with an RBE degree in May 2008, limited information is available from surveys at the present time.

Faculty

Due to the small size of the faculty, all Associated Faculty members have the opportunity to provide feedback on the RBE program. The RBE steering committee has the primary responsibility of reviewing the Educational Objectives, and evaluating and assessing the program for meeting the Objectives. Starting in January 2008, the Associated Faculty meet once per term (four times per year) to review program issues and revise aspects of the program, if deemed necessary. The steering committee meets on a more frequent basis, as required for administration and improvement of the program.

Alumni

The RBE alumni will provide a resource of information for the RBE program, through surveys and tracking of professional achievements. Each department/program creates their own survey, tailored to their program.

Process for Establishing Program Educational Objectives

<u>Relation of Objectives to Program Outcomes</u>

The WPI degree requirements, together with the RBE program distribution requirements and supported by academic planning and academic advising information, produce a curriculum which supports our educational objectives. Table 1-2 illustrates the links between our objectives and our curriculum. The curriculum and Program Outcomes should prepare students to demonstrate accomplishment of the Educational Objectives. Table 2-2 below demonstrates how the Outcomes support each Objective. The RBE curriculum and Outcomes are discussed in detail in this subsequent section. It is reasoned that a curriculum that accomplishes its Outcomes is also likely to be one that attains its Educational Objectives.

Table 4-1a: Relation of Educational Objectives to Curricular Elements

Objective	Principal Relevant Curricular Components
Have a basic understanding of the fundamentals of Computer Science, Electrical and Computer Engineering, Mechanical Engineering, and Systems Engineering.	Balanced selection of engineering science and design, computer programming and circuit design; emphasis on independent learning; MQP.
Demonstrate the ethical behavior and standards expected of responsible professionals functioning in a diverse society.	Teamwork in class and projects; substantial writing in Humanities and Arts, IQP, MQP, and laboratory classes; oral presentations; strong liberal education component.
Apply these abstract concepts and practical skills to design and construct robots and robotic systems for diverse applications.	Balance of theory and practice; independent learning in projects and outside class.
Have the imagination to see how robotics can be used to improve society and the entrepreneurial background and spirit to make their ideas become reality.	Substantial course and project work in Humanities and Arts and Social Sciences, and relation of that work to RBE major; ability to have entrepreneurial spirit

In the chart below, we follow the same steps as the chart above. The exception is that we use the new objectives that we created.

Table 4-1b: Relation of Revised Educational Objectives to Curricular Elements

Objective	Principal Relevant Curricular Components
Should be able to apply the fundamental principles of mathematics, science, and engineering to real life problems in the field of robotics engineering	Balanced selection of engineering science and design, computer programming and circuit design; emphasis on independent learning; MQP.
Should have the ability to work effectively on a team	Teamwork in class and projects; substantial writing in Humanities and Arts, IQP, MQP, and laboratory classes; oral presentations; strong liberal education component.
Should pursue lifelong learning, and prepare for immediate professional practice and continual development	Balance of applications and theoretical courses, emphasis on independent learning, in projects and outside class.
Should be able to relate the effects of his or her technological work to humankind in a positive way, and understand the impact it will have on society	Balance of theory and practice; independent learning in projects and outside class. Substantial course and project work in Humanities and Arts and Social Sciences, and relation of that work to RBE major

RBE Educational Outcomes

Based on the department's educational objectives, students will achieve the following specific outcomes within a challenging and supportive environment. These outcomes can be found on the link http://www.wpi.edu/Academics/Majors/RBE/academics.html

Graduating students will have:

1. an ability to apply broad knowledge of mathematics, science, and engineering,
2. an ability to design and conduct experiments, as well as to analyze and interpret data,
3. an ability to design a robotic system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability,
4. an ability to function on multi-disciplinary teams,
5. an ability to identify, formulate, and solve engineering problems,
6. an understanding of professional and ethical responsibility,
7. an ability to communicate effectively,
8. the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context,
9. a recognition of the need for, and an ability to engage in life-long learning,
10. a knowledge of contemporary issues, and
11. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

In the next chart, we analyzed the relationship of the educational objectives to the outcomes so that we could better understand how the objectives related back to the outcomes. We take each each objective and relate it back to its respective RBE outcome.

Table 4-2a Relation of Objectives to Outcomes

RBE Educational Objectives	RBE Program Outcomes
fundamentals of Computer Science, ECE, ME and systems engineering	1, 4, 5, 8, 10, 11
construct robots and robotic systems for diverse applications.	2, 3, 4, 5, 10, 11
demonstrate the ethical behavior and standards	6, 7
the imagination to see how robotics can be used to improve society	2, 3, 5, 8, 9
entrepreneurial background and spirit to make their ideas become reality	2, 3, 6, 7, 8, 9

In the chart below, we followed the same process above except we used the new objectives that our group had created.

Table 4-2b: Relation of Revised Objectives to Outcomes

RBE Educational Objectives	RBE Program Outcomes
fundamental principles of mathematics, science, and engineering to real life problems in the field of robotics engineering	1, 2, 3, 5, 8
Should have the ability to work effectively on a team	2, 4, 7, 11
Should pursue lifelong learning, and prepare for immediate professional practice and continual development	1, 2, 3, 4, 7, 9, 11
Should be able to relate the effects of his or her technological work to humankind in a positive way, and understand the impact it will have on society	2, 3, 5, 6, 9, 10
Should possess leadership abilities, as well as technical and nontechnical communication skills	3, 4, 6, 7

The RBE curriculum is described in detail under Section 3. The structure and content of the curriculum directly addresses our stated objectives. As a result of the WPI general Degree Requirements and the RBE Distribution Requirements, a basic process is in place to assure that all students complete the curriculum with appropriate components to their education and standards of performance. Further, as described below, a system of ongoing evaluation is used to collect information related to accomplishment of educational objectives over the longer term, and to validate the performance of our curriculum against our educational objectives.

Achievement of Program Educational Objectives

Our plan for evaluating the extent to which the educational objectives in Robotics Engineering are being met is described here. As the RBE program is new at WPI, we have not yet been able to implement the entirety of this plan. We have adopted the common view that Educational Objectives refer to characteristics and abilities demonstrated by our alumni in the initial years after completion of the RBE program. We evaluate the achievement of these Objectives in three fundamental ways:

- Data from our Outcomes Assessment process since our Program Outcomes should prepare graduates to demonstrate Educational Objectives;
- Initial and continuing career success of our graduates; and
- Feedback from our alumni, employers and Advisory Board.

Several time scales are involved in evaluation of objectives. First, we wish to determine that the curriculum is providing an education which can be expected to lead to achievement of the stated Objectives. Second, we wish to verify that students are learning the desired aspects. Third, we wish to verify that our alumni are displaying results consistent with the Objectives in their professional lives. The tools we plan to use in evaluating achievement of our Educational Objectives are:

- Alumni surveys conducted 2, 5, and 8 years after graduation;
- Alumni career data; and
- Input from Advisory Board Members.

Evidence for accomplishment of Program Outcomes, which leads to accomplishment of Educational Objectives, is described in Section 3 (Program Outcomes) of this Self-Study Report. With respect to graduates of the RBE program, it is too early to conduct an analysis as the first graduate received a Robotics Engineering degree in May 2008; however, the process by which Objectives will be evaluated in the future is discussed here.

Objective 1: Have a basic understanding of the fundamentals of Computer Science, Electrical and Computer Engineering, Mechanical Engineering, and Systems Engineering.

In order for RBE majors to fully comprehend the fundamentals of the major, they must be able to prove that they have a sufficient knowledge in computer science, electrical and computer engineering, mechanical engineering and systems engineering. They must have a balanced selection of engineering science and design, computer programming and circuit design. This balance will include the basic ideas of the three encompassing majors of the RBE major. These requirements ensure that all RBE students study the breadth of the RBE field and pursue topics in depth as well.

The RBE program distribution requirements are provided in Section 3 of this report and discussed in detail there. Briefly, the RBE program requires 4 units (12 courses) in basic math and science, 1 unit (3 courses) in advanced science, and 6 units (18 courses or course equivalents) in engineering science and design. The ABET specific capstone design requirement is encompassed by the distribution requirements and the WPI requirement for completion of the MQP.

Objective 2: Demonstrate the ethical behavior and standards expected of responsible professionals functioning in a diverse society.

Effective communication, essential for success, requires facility in both written and oral communication. The main opportunities for students to develop written communication skills are the Humanities and Arts requirement, the IQP, the MQP, and courses with intensive writing experiences, such as laboratory courses. Oral communication is stressed in the MQP and is often required for the IQP. Furthermore, there is a day set aside in April at WPI called Project Presentation Day when no classes are held and most students make presentations of their MQP work. The laboratory component of the RBE curriculum discussed in Section 3 of this report clearly addresses the first part of Objective 2.

Ethics and professional issues are also a key component of the WPI RBE education. Students develop a broad background in the social and ethical implications of their work through a number of different mechanisms. These include the IQP, Humanities and Arts requirements, Social Sciences requirements, and project work in the RBE major. Lastly, a professional attitude is gained through independent work and teamwork, associations with sponsors on MQPs, and other events, such as seminar speakers, involvement in student organizations, and job fairs, that are a regular part of the WPI educational experience.

Objective 3: Apply these abstract concepts and practical skills to design and construct robots and robotic systems for diverse applications.

With the knowledge specified in Objective 1, all students who have graduated from WPI will have had some experience in designing and constructing robotic systems. As their experience grows, they should be able to look back on the abstract concepts and practical skills that they learned at WPI and relate them to more complex robotic systems. This will allow our graduates to take a more in-depth look at the concepts that they learned and expand upon them in a real world environment.

Objective 4: Have the imagination to see how robotics can be used to improve society and the entrepreneurial background and spirit to make their ideas become reality.

The two major required projects (MQP, IQP), seminars, reinforcement of state of the art classes, and informal discussions on our graduate programs and other post-BS degree opportunities form the basis for informing our students about graduate study and life-long learning opportunities. These classes give our students the proper attitude that they will need to understand how the real world runs and the imagination for how robotics can improve society and what they can do to help influence it.

Tools for Evaluating Achievement of Objectives

Alumni Surveys

Each department or program may conduct an alumni survey that can be used to assess attainment of Educational Objectives. A draft alumni survey for the RBE program is provided in Appendix B. Surveys will be conducted of alumni who have been out 2, 5 and 10 years. As there were only four graduates of the RBE program in 2008, we already have an alumni survey that has gone out for those students and the 2-year survey will be initiated with the class of 2009 in the year 2011. In 2006, the Electrical and Computer Engineering (ECE) Department at WPI established a method for performing on-line, efficient, internet based surveys of alumni. They found that the turn around time was on the order of a few weeks. Because of the success of this approach to surveying, the ECE Department has shared this method with other departments at WPI and has in fact hosted surveys for other departments when requested. Thus, the RBE program anticipates using an on-line survey mechanism with the assistance of the ECE Department. As seen in Appendix B, the alumni survey is designed to obtain data concerning:

- basic student data (degree year, focus area, majors, minors, etc.),
- continuing education (degrees, area),
- current work status (level, title, company, working as an engineer or not, employed or not, etc.),
- student perceptions of how well the program achieves its stated program educational objectives,
- student perceptions of how well the program achieves the goals of the MQP (a superset of the ABET capstone project),
- various questions concerning how well WPI is achieving goals related to the IQP (global awareness, ability to work across time and space, team work, cultural sensitivity, etc.),

A review of the data from these surveys will provide information on two different aspects of the RBE program:

(1) the relative importance that our alumni place on the various components of our Educational Objectives, and

(2) the alumni view of their preparation.

With regard to program improvements, the greatest attention will be paid to area of high importance in which the preparation is rated relatively low. It is also a matter of concern if our constituents (alumni in this case) rate an aspect of our Objectives as relatively unimportant, regardless of their view of the preparation in that element. Survey responses will be collected on a seven point scale (1 = not at all; 7 = very much).

Alumni Career Data

The Career Development Center (CDC) distributes annual statistics for students who register with their office. Information collected and analyzed by the CDC includes the percentage of the

graduating class placed in the workforce, military or graduate school and starting salaries. As one example of the usefulness of this information, comparison of starting salaries of WPI graduates with national averages can provide information on the value of a WPI education to employers. After graduation, the WPI Alumni Association keeps in relatively close touch with our graduates, which results in useful information regarding overall career paths and career success. This provides a broad look at our graduates in successive years post-graduation. At this time, there is no alumni data to report on, as the first RBE majors graduated in May 2008.

Advisory Board Input

As described above regarding constituent involvement, the RBE Advisory Board addresses topics related to the undergraduate program at each of its twice-yearly meetings. In March 2008, the board noted that the program has a strong fundamental core that is needed for robotics engineers, and appropriate flexibility for selection of electives. The board also provided several suggestions regarding simplification of the distribution requirements and having a forward-thinking view of the robotics engineering profession. This feedback will be discussed by the RBE faculty at regularly scheduled faculty meetings during the 2008-09 academic year.

Conclusions Regarding Objectives

While a significant amount of objective data will be available regarding the manner and degree to which our graduates achieve our Educational Objectives, it is not possible to attempt to quantify each aspect. Via the program outcomes, as well as the quality of the entering students and the overall educational environment during their college experience, we have confidence that our graduates will be prepared to accomplish our objectives. We anticipate that alumni surveys, reviews of alumni career data, and input from our constituents will provide evidence that our graduates are in fact accomplishing our objectives.

4.2.2 Section 3

When looking at the ECE self study, we realized that there are a few parts that we could not fill in with the information that we had so we filled some parts into this paper with the expected comments that need to be made in the self study. The parts that we believed should be put into Section 3 of the self study are bracketed below.

CRITERION 3. PROGRAM OUTCOMES

[Program outcomes: Narrower statements that describe what students are expected to know and be able to do by the time of graduation (skills, knowledge, and behaviors students acquire throughout the program).]

Outcomes of the Robotics Engineering Program

[List the Program Outcomes and describe how they encompass Criterion 3 and any applicable Program Criteria. Indicate where the Program Outcomes are documented.]

The WPI Robotics program has chosen to use the standard educational outcomes for engineering programs, provided by ABET's Criterion 3a-k. Following are the outcomes of the Robotics

Engineering Program as adopted by the RBE faculty on _____. Based on the stated objectives, students will achieve the following specific educational outcomes:

Graduating students will have:

- an ability to apply broad knowledge of mathematics, science, and engineering,
- an ability to design and conduct experiments, as well as to analyze and interpret data,
- an ability to design a robotic system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability,
- an ability to function on multi-disciplinary teams,
- an ability to identify, formulate, and solve engineering problems,
- an understanding of professional and ethical responsibility,
- an ability to communicate effectively,
- the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context,
- a recognition of the need for, and an ability to engage in life-long learning,
- a knowledge of contemporary issues, and
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

RBE program outcomes are documented in our undergraduate catalog, and our web page for undergraduate robotics engineering, located here: http://www.wpi.edu/academics/Majors/RBE/academics.html.

Relation of Program Outcomes to ABET Requirements

The Outcomes from ABET Criterion 3 are listed below for reference:

A. An ability to apply knowledge of mathematics, science, and engineering
B. An ability to design and conduct experiments, as well as to analyze and interpret data
C. An ability to design a system, component, or process to meet desired needs
D. An ability to function on multi-disciplinary teams
E. An ability to identify, formulate, and solve engineering problems
F. An understanding of professional and ethical responsibility
G. An ability to communicate effectively
H. The broad education necessary to understand the impact of engineering solutions in a global and societal context
I. A recognition of the need for, and an ability to engage in life-long learning
J. A knowledge of contemporary issues
K. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

The eleven WPI RBE Program Outcomes are meant to directly match all of the ABET Outcomes (a-k), while at the same time encompassing WPI's Mission and Goals.

Relation of RBE Program Outcomes and RBE Educational Objectives

[Describe how the Program Outcomes lead to the achievement of the Program Educational Objectives.]

The Program Outcomes are chosen so that they are demonstrable by students upon graduation, whereas the Program Educational Objectives are intentionally more broad, long range, and as a consequence somewhat more difficult to measure quantitatively. Nevertheless, the Outcomes were chosen to provide an education which should lead to demonstration of the desired Objectives.

Relationship of Courses to Program Outcomes

Below, each of our program outcomes is related to a component (or components) of the WPI plan and RBE courses. Below the required third year project (IQP) and fourth year project (MQP) are described.

The Interactive Qualifying Project (IQP)

At WPI, students are expected to develop an understanding of how science and technology are embedded in the fabric of society. The Interactive Qualifying Project (IQP) challenges students to address a problem that lies at the intersection of science or technology with society. During the IQP, students work in interdisciplinary teams, often with an external sponsoring organization, to develop solutions to real world problems. In doing so, students learn something about the role of science and technology, its impact on society, its place in meeting human needs and human efforts to regulate, control, promote and manage our changing technologies.

The Major Qualifying Project (MQP)

The qualifying project in the major field of study should demonstrate application of the skills, methods, and knowledge of the discipline to the solution of a problem that would be representative of the type to be encountered in one's career. The project's content area should be carefully selected to complement the student's total educational program. In defining the project area within which a specific topic is to be selected, the student and academic advisor should pay particular attention to the interrelationships that will exist between the bodies of knowledge represented by courses, independent studies, and Preliminary Qualifying Projects; and by the Interactive Qualifying Projects. MQP activities encompass research, development, and application, involve analysis or synthesis, are experimental or theoretical, emphasize a particular subarea of the major, or combine aspects of several subareas. In many cases, especially in engineering, MQP"s involve capstone design activity. Long before final selection of a project topic, serious thought should be given as to which of these types of activities are to be included. Beyond these considerations, the MQP can also be viewed as an opportunity to publish, to gain experience in the business or public sectors.

The following indicates how our outcomes are met by portions of the WPI Plan.

Table 3.2 Relationship Between Program Outcomes and WPI /ECE Degree/Curriculum Components

RBE Program Outcome	WPI/RBE Curriculum/Plan Component
1. An ability to apply knowledge of mathematics, science, and engineering	mathematics and science distribution requirements
2. An ability to design and conduct experiments, as well as to analyze and interpret data	
3. An ability to design a robotic system, component, or process to meet desired needs	
4. An ability to function on multi-disciplinary teams	RBE courses, **IQP**, **MQP**
5. An ability to identify, formulate, and solve engineering problems	
6. An understanding of professional and ethical responsibility	various course and team projects, **IQP**, **MQP**, humanities and arts requirement, major area courses, written and oral communications requirements
7. An ability to communicate effectively	**IQP**, **MQP**, humanities and arts requirement, project presentation day

8. The broad education necessary to understand the impact of engineering solutions in a global and societal context	WPI global program, **IQP, MQP** (particularly those off campus), HU&A requirements, RBE courses, Social Implications of Technology requirement
9. A recognition of the need for, and an ability to engage in life-long learning	
10. A knowledge of contemporary issues	
11. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.	

In this next section below, we were not able to collect the proper information for the RBE major. Therefore, we took the section from the ECE self study that we believed needed to be in the RBE self study report. The section is called *Overview of the Curricular Development and Assessment Process.*

Overview of the Curricular Development and Assessment Process

Structure

Development, implementation and assessment of the ECE program are the explicit responsibility of the ECE Undergraduate Program Committee (UPC) and Curriculum Committee (CC), and are managed by the ECE Department Head with the support of the Associate Head. **UG Program Committee**: manages all non-course program issues including projects (assignments, management, support), academic advising day, minors, and project presentation day, etc.

Curriculum Committee: manages all aspects of undergraduate and graduate curriculum, courses, tracks, on- and off-campus offerings, course and project outcomes and assessment; course descriptions; implementation of strategic plan, etc.

These committees consists of the committee chair, the Associate Head ex-officio (for CC), and to the extent possible a representative of department emphasis areas (fundamentals, computer engineering, electromagnetics, communications and signal processing, power systems, analog microelectronics). Both the UPC and CC appoint ad-hoc committees as appropriate to address specific topics. A long running example is the ad-hoc committee to review computer engineering courses, labs and projects (the Computer Engineering Review Committee - CERC) which monitors all aspects of the computer/digital area courses/projects and which meets sufficiently regularly to insure that the quality of the digital/computer engineering (D/CE) courses are kept up to date, that the associated course laboratories are well planned, supported, stocked and staffed, and that there are excellent resources available for project activities ranging from capstone (undergraduate) projects to MS and Ph.D. thesis and dissertation activities, respectively.

Process

Recommendations for changes in the undergraduate program for non-course related topics are first reviewed and voted by the UPC (curriculum topics are managed by the CC) and then discussed and acted on by the entire ECE faculty. Also, major changes are discussed with the departmental Advisory Board and with the students. Minutes of the UPC and CC meetings and ad hoc committee reports will be available at the visit. The first step of our curriculum development has been to identify the kinds of skills and abilities we wish our students to exhibit when they graduate. We then plan for ways that our students could prepare for and then exhibit this evidence multiple times whenever possible. Here, by skills and abilities we mean both specific skills such as those that might be taught (for example) in a course on circuit theory (e.g. in-depth knowledge in a specific area) as well as broader types of skills and abilities such as good written and oral communication skills. Our approach to assessment of what we deem desirable skills and abilities (within the context of our program outcomes) has been to provide mechanisms for determining student performance throughout their academic program, to report the findings in a timely and constructive way, to determine and obtain relevant comparisons for the data received, and to provide anonymity to students as they fill out survey tools. These mechanisms, in turn, provide ways to collect evidence of those skills and abilities. Finally, the evidence is used in a circular manner, once reviewed, to modify how we implement our program to foster those skills and abilities in our students so that i) we have high confidence that our students are actually obtaining those desirable skills and abilities (our outcomes) and ii) how we collect our evidence (our assessment mechanisms) so that we have confidence and efficiency in our data collection processes.

The overall departmental process for curricular planning, assessment and quality improvement is shown on the following page in **Figure 3.1** (*also*, **Appendix G**) and is based on the department head (DH) and associate head (AH) reviewing collected assessment material and then, as necessary, discussing the evidence with appropriate committee chairs and establishing a plan for action. On occasion, an ad-hoc committee may also be formed to discuss the issue(s), formulate a solution, and monitor implementation. The bottom line is that the DH and AH manage the exchange of information among faculty (as committee members, course instructors, project advisors and academic advisors), students (in courses, on projects, as leaders, and during their extra-curricular activities), and the assessment tools (that address all of these aspects). The

assessment tools are administered and the reporting done in a timely way so that the process is part of our culture, not appended to it.

Outcomes Development and Assessment

Describe the process used for establishing and revising Program Outcomes. Describe by example how the evaluation team will be able to relate the display materials, i.e., course syllabi, sample student work, etc., to each Program Outcome.

The guiding principles for the work reported here are based on the following (slightly modified) steps for developing an assessment plan33:

1. identify goals and objectives

2. identify desirable **outcomes**

3. determine **evidence** needed to verify outcomes

4. specify **assessment methods** to obtain evidence

5. develop **connections** between evidence and assessment (particularly if indirect)

6. determine **feedback channels** to provide for continuous improvement

7. conduct assessments

8. **evaluate** assessment results, determine opportunities and take appropriate action

Identify Goals and Objectives - *Step 1*

The result of this process can be found in the section on Criterion 2 of this report, where the Mission and Goals of WPI and the Objectives for the ECE program are stated.

Identify Outcomes - *Step 2*

Our program outcomes can be found in this Section.

Determine Evidence - *Step 3*

Much of our evidence is based on outcomes of coursework, MQPs, and IQPs, which in turn constitute degree requirements. Other evidence is provided through student surveys and internal reporting. A listing of the general evidence identified for each program outcome can be found in **Table 3.3**. Specific evidence is reviewed on pages 56-60. Briefly, **Table 3.3** lists the sources of evidence such as courses, surveys and other tools that are used in different ways and with different emphasis to help us understand the extent to which we are achieving specific outcomes. The information provided on pages 56-60 breaks down each outcome into different categories or aspects of each outcome and relates the category/aspect to specific evidence.

Table 3.3 Assessment Matrix for Program Outcomes.

RBE Program Outcome	Assessment Evidence Source or Tool
1. An ability to apply knowledge of mathematics, science, and engineering	MQP Inventories Course outcome data
2. An ability to design and conduct experiments, as well as to analyze and interpret data	
3. An ability to design a robotic system, component, or process to meet desired needs	
4. An ability to function on multi-disciplinary teams	MQP inventories
5. An ability to identify, formulate, and solve engineering problems	
6. An understanding of professional and ethical responsibility	MQP and IQP reviews Faculty MQP reviews Course outcome data
	MQP inventories

7. An ability to communicate effectively	MQP and IQP reviews MQP oral presentation evaluations
8. The broad education necessary to understand the impact of engineering solutions in a global and societal context	MQP inventories
9. A recognition of the need for, and an ability to engage in life-long learning	
10. A knowledge of contemporary issues	
11. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.	

Specify Assessment Methods - Step 4

This section describes the assessment tools referred to in **Table 3.3**.

Educational Benchmarking Survey - Performed at WPI and other schools in 2006 and 2007. Data is available from all of the schools that participated in the study. Charts are shown comparing WPI to "Select 6" (2006: BU, Northeastern, Rice, CMU, Kettering, Stevens - - 2007: BU, CMU, Dartmouth, Drexel, Northeaster, MIT)34 and "Carnegie Class" (2006: Dartmouth, George Mason, Texas A&M Kingsville, Florida Atlantic, Stevens, Texas Christian, U. Dayton, San Diego, Texas Dallas - - 2007: Cal State LA, Cal State Northbridge, Gonzaga, Loyola Marymount, National U., Santa Clara, U. Tenn. at Chattanooga, Villanova). EBI survey summary results for all departments participating in the survey are summarized in **Appendix L.3.B**. A sample of the EBI survey form is found in **Appendix L.3.A**. A full copy of the EBI results is approximately 600+ pages and will be made available to the ABET visitors if requested.

Alumni Survey - Details of the alumni survey have been described previously (p.42).

Senior Survey - Performed by the ECE department annually since 1996. An example of the form used and the results can be found in **Appendix L.2.A** and **L.2.B**, respectively. Changes over the years have reflected that a number of the questions have been answered by the EBI survey, and others have been added to provide a more complete assessment of the students" experience.

WPI Teaching Evaluations - includes data collected for the entire department, and results presented are the percentages of responses that are Strongly Agree or Agree. The total number of responses for each question has excluded Not Application (NA) responses for lab/facilities related questions. Values are for all RBE courses in an academic year, and are compared to courses from other WPI engineering departments in the same academic year. The return rates vary from one course offering to the next, but are generally fairly high because the forms are distributed during a lecture. An example of the form used and the results can be found in **Appendix H.1.**

Course Based Assessment - refers to assessments done in ECE courses. Our department has targeted seven courses for course-based assessment (ECE 2011, ECE 2022, ECE 2201, ECE 2311, ECE 2111, ECE 2799, and ECE 2801). We developed a set of course outcomes which remain the same for each course offering. The actual coverage of material in each course is, however, more comprehensive than this set. Course instructors have the tasks of matching evaluated student performance (such as exam questions) to each course outcome and keeping student-specific data on performance. Summary data for all assessed courses is provided in **Appendix I.3**.

Faculty Two Page Course Review Sheet - a relatively new and valuable per-course-offering review sheet filled out by faculty at the end of every ECE course offering. This review sheet, copies of which will be available and an example of which is found in **Appendix J**, seeks to determine whether a particular offering of a course is achieving the desired outcomes from the faculty perspective and how well the students are prepared for the course. As a result, this review sheet provides a viable way to determine the impact of individual course offerings, student quality, student preparation and to identify problems both on an individual course basis, as well as how courses flow together, and how possible problems ripple through out curriculum.

MQP Inventory and Assessment - is done in a variety of ways and is appropriate given the importance of this degree requirement. Since 1999, the project advisor has been asked to complete MQP inventories near the end of each project. The current version of the forms can be found in **Appendix K.1.C**. Tabulations of some of the data collected can be found in **Appendix K.1.D**.

Separate from these inventories, a MQP review committee provides evaluations on a range of topics. The MQP review committees have been operating essentially biennially since 1997. A copy of their latest report can be found in **Appendix K.2**. MQP teams are required to do an oral presentation, and these presentations usually occur on one of two department-wide project presentation days (fall, spring). Oral presentation skills are assessed during these days by faculty in attendance. An example of the form used and results can be found in **Appendix K.3.A** and a summary of the data can be found in **Appendix K.3.B**.

RBE TA and Senior Tutor Evaluations - are completed by course instructors and collected by the department. An example of the form used and the results can be found in **Appendix F**.

Develop Connections - *Step 5*

There are two important layers of our assessment program:

1. The links between the outcomes and the ways in which students provide *evidence* that they have achieved the outcome.

2. The links between this evidence and assessment methods.

3. The links between the evidence and how the evidence is processed to create continuous improvement feedback paths.

It was agreed that there would be a *framework* for assessment so that any minor changes need not be approved by the ECE Curriculum Committee before being implemented. An important feature of this framework, shown in **Figure 3.1** is that it describes which tool(s) are needed for each kind of evidence (and in turn each outcome). In order to specifically address *connections* between tools and evidence, the eleven ECE Program Outcomes are listed below, together with some of the evidences of achievement and the method by which the assessment takes place. The abbreviations used for assessment methods are: **ALS** (Alumni Survey), **DAR (**Department Head and Associate Department Head Review), **EBIA** (EBI Engineering Exit Assessment), **OPA** (Oral Presentation Assessment), **MQPA** (Senior Design Project Assessment), and **SNS** (ECE Senior Survey).

For these upcoming charts, we were not able to obtain any of the information necessary to fill in these charts. They were taken from the ECE self study and placed within the RBE self study.

Outcome 1: An ability to apply broad knowledge of mathematics, science, and engineering.

Evidence	Assessment Method

Outcome 2: An ability to design and conduct experiments, as well as to analyze and interpret data.

Evidence	Assessment Method

Outcome 3: An ability to design a robotic system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.

Evidence	Assessment Method

Outcome 4: An ability to function on multi-disciplinary teams.

Evidence	Assessment Method

Outcome 5: An ability to identify, formulate, and solve engineering problems.

Evidence	Assessment Method

Outcome 6: An understanding of professional and ethical responsibility.

Evidence	Assessment Method

Outcome 7: An ability to communicate effectively.

Evidence	Assessment Method

Outcome 8: The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.

Evidence	Assessment Method

Outcome 9: recognition of the need for, and an ability to engage in life-long learning.

Evidence	Assessment Method

Outcome 10: A knowledge of contemporary issues.

Evidence	Assessment Method

Outcome 11: An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Evidence	Assessment Method

Determine Feedback Channels - *Step 6*

Oversight of the assessment reporting is provided by the Department Head and Associate Head. As noted earlier, the DH and AH review the collected assessment material and then, as necessary, discuss the evidence with appropriate committee chairs and establish a plan for action. As noted in **Figure 3.1** and shown in **Table 3.4**, once the assessment data is reviewed by the DH and AH, it is forwarded to the appropriate individual(s) or committee and discussed. It is then the committee/individual(s) responsibility to review the material, determine the need and method for action, recommend a plan, and act on it in some manner.

Conduct Assessments – *Step 7*

Table 3.4 shows the different assessment methods used and the schedule of their implementation.

Evaluate Results – *Step 8*

This section documents *some* of the results that have been attained through our process of assessment, reporting, and action.

Assessment of the **MQP** in 2004 and 2006 showed a number of interesting trends and results when comparing the two surveys to each other.

Senior Survey results are available for every year since the last ABET visit. Representative results noted below are from the 2008 survey of graduating seniors. In the following data the scale is ranked from 1=inadequate, 3=adequate and 5= excellent.

Oral presentation reviews (Project Presentation Day) comments showed that there was a marked improvement in the quality of the MQP presentations in 2008. In particular, we had observed presentation quality declined in 2007 compared to 2006 and it has been noted that the oral MQP

Presentations seemed to need more faculty input to improve the quality. After a concerted effort by the department head to remind faculty to rehearse their students and properly prepare them for their oral presentations, it was noted (by the DH in an email to his colleagues) that the quality of the presentations were improved in 2008 and that he had not attended a single presentation that was not well done.

Continuous **review of our curriculum** and courses highlighted opportunities for improvement in both our early entry courses (first and second years) as well as our more advanced courses - a bimodal concern by our students (exit surveys, senior surveys, alumni surveys). As a result, for example, we i) implemented a new first year seminar ECE 1799 that we are still evolving and optimizing, ii) have reviewed the content of our early circuits courses (ECE 2011, 2111) and are making appropriate changes, iii) deleted a few courses in areas that are out of date or in need of replacement and created several new courses in topical areas such as wireless networks, and iv) looking at how to improve the flow between our upper level UG courses and our lower level graduate level courses.

Feedback from faculty member **two page course reviews** have revealed a disconnect between what we want students to learn in our early circuits courses (2011, 2111) and what they seem to retain for follow on courses. Representative issues include basic circuit analysis knowledge, the proper use of simulators, and the ability to perform goal oriented design. As a result, we are making changes to our early circuits courses and re-evaluating our laboratory goals to better reinforce course outcomes.

The department has continued to support **student groups**, in particular contributing to the creation of a new ECE student advisory board and providing funding for numerous student events (e.g. Spark Party). Indeed, at the recent senior student banquet the DH received the outstanding student service award for the year for his strong support of all ECE student groups and "having never said no to any request from an ECE student group".

In this upcoming section, we did the same thing as we did before. We took the proper section from the ECE self study and placed them within the RBE self study. The section that we took from the ECE self study is titled *Achievement of Program Outcomes*.

Achievement of Program Outcomes

Explain the assessment and evaluation processes that periodically document and demonstrate the degree to which the Program Outcomes are attained. Describe the level of achievement of each Program Outcome. Discuss what evidence will be provided to the evaluation team that supports the levels of achievement of each Program Outcome.

This section looks at data and answers the question "*Is our program meeting its desired outcomes?*" This analysis is documented below for each of the RBE program outcomes. References are made to assessment results – which can be checked by looking at the appropriate appendix for the assessment tool or appropriate outcome report.

Our assessment of MQPs by advisors is used throughout this section. This is done by examining the *percentage of projects* that have a given quality at least to a "somewhat" level of compliance[35] or achievement, and the *percentage of students* judged to be on a level of 2 or higher out of 5.[36]

Outcome 1: An ability to apply knowledge of mathematics, science, and engineering

    Explanation of evidence goes here.

Outcome 2: An ability to design and conduct experiments, as well as to analyze and interpret data

    Explanation of evidence goes here.

Outcome 3: An ability to design a system, component, or process to meet desired needs

    Explanation of evidence goes here.

Outcome 4: An ability to function on multi-disciplinary teams

    Explanation of evidence goes here.

Outcome 5: An ability to identify, formulate, and solve engineering problems

    Explanation of evidence goes here.

Outcome 6: An understanding of professional and ethical[1] responsibility

    Explanation of evidence goes here.

Outcome 7: An ability to communicate effectively

    Explanation of evidence goes here.

Outcome 8: The broad education necessary to understand the impact of engineering solutions in a global and societal context

    Explanation of evidence goes here.

Outcome 9: A recognition of the need for, and an ability to engage in life-long learning

    Explanation of evidence goes here.

Outcome 10: A knowledge of contemporary issues

    Explanation of evidence goes here.

Outcome 11: An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

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[35] Levels range from "none" to "little", "somewhat", "much" and "very much".

[36] Levels range from "1" meaning a first year course knowledge/effort to "5" representing a graduate level effort/knowledge.

5 Analysis of Results

In this section, we analyze our surveys as well as sections 2 and 3 of the RBE self study that we have written. In our analysis, we discuss the problems that we noticed within the unified robotics courses as well as ways for them to be fixed.

5.1 Analysis of Survey Results

The surveys conducted throughout this project gave very interesting and useful results. The graphs produced by these results, as displayed in section 4.1, will be very useful additions to parts of the RBE Self Study. The trends observed in the results of the surveys are beneficial for both the self study report, and the program itself for discovering areas of the program in need of improvement.

The results of the Introduction to Robotics Engineering course surveys showed trends of most confidence in mechanical systems, and least confidence in areas of electrical and control system design. These trends change as you move through the Unified Robotics courses. The Unified Robotics II survey results produced trends of high confidence in mechanical systems again, and even less confidence in electrical systems. But also, less confidence in the algorithms and programming concepts introduced in the course. The biggest shift in trend occurred with the Unified Robotics IV course survey results. The results for this course showed that students were least confident in electrical and mechanical systems and design, and most confident in programming and testing.

Comparing the survey results to the curriculum and outcomes of the courses provided some insight into where improvements might be made. As the course series progressed, there is a decrease in focus on mechanical systems and design, and an increase in programming and electrical emphasis. The lesser confidence shown in these areas by students who have completed the Unified Robotics IV course is not of a concerning level. Many students indicated the highest level of confidence in the mechanical and electrical areas; however, more students responded with a confidence level lower, such as 4 or 5, than in other areas. It was noticed that less emphasis is placed on mechanical design in the Unified III and IV courses, which may be the reason some students indicated a lower confidence level in these areas in the context of these courses. A suggestion to improving student confidence in these areas would be to increase the material covered, or time spent on the material in the mechanical and electrical areas.

Successful areas shown in the survey results were, as mentioned previously, the programming and testing areas. From looking at the curriculum for the courses, a significant amount of course time, and more specifically lab time, was spent on programming and testing. The correlation between the two is obvious; the topics the students had more time to experience in labs, were the topics they were most confident in.

5.2   Analysis of Section 2 of the RBE Self Study

This section focused around the Robotics Engineering program's educational objectives and how these objectives correlate to the ABET 3a- 3k criteria and how they are being met at Worcester Polytechnic Institute. The Educational Objectives for the Bachelor Degree in Robotics Engineering are that all graduates:

1. Have a basic understanding of the fundamentals of Computer Science, Electrical and Computer Engineering, Mechanical Engineering, and Systems Engineering.
2. Apply these abstract concepts and practical skills to design and construct robots and robotic systems for diverse applications.
3. Have the imagination to see how robotics can be used to improve society and the entrepreneurial background and spirit to make their ideas become reality.
4. Demonstrate the ethical behavior and standards expected of responsible professionals functioning in a diverse society.

These objectives map to the ABET 3a- 3k criteria in the following table.

RBE Educational Objectives	RBE Program Outcomes
fundamentals of Computer Science, ECE, ME and systems engineering	1, 4, 5, 8, 10, 11
construct robots and robotic systems for diverse applications.	2, 3, 4, 5, 10, 11
demonstrate the ethical behavior and standards	6, 7
the imagination to see how robotics can be used to improve society	2, 3, 5, 8, 9
entrepreneurial background and spirit to make their ideas become reality	2, 3, 6, 7, 8, 9

The objectives that were listed above do map to the ABET criteria, but our group created a new set of objectives that we believe better incorporate the true objectives of the RBE program. These objectives are listed below.

1. Should pursue lifelong learning, and prepare for immediate professional practice and continual development
2. Should be able to apply the fundamental principles of mathematics, science, and engineering to real life problems in the field of robotics engineering
3. Should have the ability to work effectively on a team
4. Should be able to relate the effects of his or her technological work to humankind in a positive way, and understand the impact it will have on society
5. Should possess leadership abilities, as well as technical and nontechnical communication skills

These objectives were designed by taking the educational objectives of the three majors that encompass the RBE major and finding correlations between them. These objectives map to the ABET criteria in the following table.

RBE Educational Objectives	RBE Program Outcomes
fundamental principles of mathematics, science, and engineering to real life problems in the field of robotics engineering	1, 2, 3, 5, 8
Should have the ability to work effectively on a team	2, 4, 7, 11
Should pursue lifelong learning, and prepare for immediate professional practice and continual development	1, 2, 3, 4, 7, 9, 11
Should be able to relate the effects of his or her technological work to humankind in a positive way, and understand the impact it will have on society	2, 3, 5, 6, 9, 10
Should possess leadership abilities, as well as technical and nontechnical communication skills	3, 4, 6, 7

The ME, ECE and CS courses that make up the RBE curriculum are taught very thoroughly and have been improved on greatly. There are many factors that make up how these educational objectives are met. The actual set of objectives meets the ABET criteria in many different ways.

In order to accomplish objective 1, WPI has specific distribution requirements. The RBE program distribution requirements are provided in Section 3 of this report and discussed in detail there. Briefly, the RBE program requires 4 units (12 courses) in basic math and science, 1 unit (3 courses) in advanced science, and 6 units (18 courses or course equivalents) in engineering science and design. The ABET specific capstone design requirement is encompassed by the distribution requirements and the WPI requirement for completion of the MQP.

In order to accomplish objective 2, WPI sets standards of ethical behavior and communication abilities. The main opportunities for students to develop written communication skills are the Humanities and Arts requirement, the IQP, the MQP, and courses with intensive writing experiences, such as laboratory courses. Oral communication is stressed in the MQP and is often required for the IQP. Ethics and professional issues are also a key component of the WPI RBE education.

In order to accomplish objective 3, WPI makes sure that there is plenty of group and hands on work. With the knowledge specified in Objective 1, all students who have graduated from WPI will have had some experience in designing and constructing robotic systems. As their experience grows, they should be able to look back on the abstract concepts and practical skills that they learned at WPI and relate them to more complex robotic systems.

In order to accomplish objective 4, WPI has many projects that allow their students to expand upon their knowledge from the past, at the present and in the future. The two major required projects (MQP, IQP), seminars, reinforcement of state of the art classes, and informal discussions on our graduate programs and other post-BS degree opportunities form the basis for informing our students about graduate study and life-long learning opportunities. These classes give our students the proper attitude that they will need to understand how the real world runs and the imagination for how robotics can improve society and what they can do to help influence it.

There is a great deal of data that goes into these objectives to make sure that they are met to both the standards of WPI as well as ABET. WPI uses alumni surveys, career data and advisory board input so that these objectives are well thought out and well rounded. While a significant amount of objective data will be available regarding the manner and degree to which WPI's graduates achieve the Educational Objectives, it is not possible to attempt to quantify each aspect. Via the program outcomes, as well as the quality of the entering students and the overall educational environment during their college experience, WPI has a great deal of confidence that their graduates will be prepared to accomplish the objectives set forth.

5.3   Analysis of Section 3 of the RBE Self Study

This section focused on the robotics program's educational outcomes and how these outcomes correlate to the ABET 3a- 3k criteria and how they are being met at Worcester Polytechnic Institute. The Educational Outcomes for the Bachelor Degree in Robotics Engineering are that all graduating students will have:

A. An ability to apply broad knowledge of mathematics, science, and engineering,
B. An ability to design and conduct experiments, as well as to analyze and interpret data,
C. An ability to design a robotic system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability,
D. An ability to function on multi-disciplinary teams,
E. An ability to identify, formulate, and solve engineering problems,
F. An understanding of professional and ethical responsibility,
G. An ability to communicate effectively,
H. The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context,
I. A recognition of the need for, and an ability to engage in life-long learning,
J. A knowledge of contemporary issues, and
K. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

These outcomes are nearly identical to the ABET 3a- 3k criteria, listed below (words the RBE Program added to their outcomes are written in bold text):

A. An ability to apply knowledge of mathematics, science, and engineering
B. An ability to design and conduct experiments, as well as to analyze and interpret data
C. An ability to design a **robotic** system, component, or process to meet desired needs **within realistic constraints such as economic, environmental, social, political, ethical, health, and safety, manufacturability, and sustainability**,
D. An ability to function on multi-disciplinary teams
E. An ability to identify, formulate, and solve engineering problems
F. An understanding of professional and ethical responsibility
G. An ability to communicate effectively
H. The broad education necessary to understand the impact of engineering solutions in a global, **economic, environmental,** and societal context
I. A recognition of the need for, and an ability to engage in life-long learning
J. A knowledge of contemporary issues **and**
K. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

The drafted Section 3 of the robotics ABET report is about showing how the WPI/RBE Curriculum and other Plan Components allow for the fulfillment of the 3a-k criteria. WPI's Humanities and Arts Requirement, Interactive Qualifying Project, and Major Qualifying Project aid in the meeting of some Program Outcomes, but other evidence was needed to vouch for the others.

To assist the robotics program in proving that they were meeting the other Program Outcomes, we broke down each of the five main robotics courses' (RBE 1001, 2001, 2002, 3001, and 3002) syllabus course outcomes and surveyed the students on them. They were asked their confidence of multiple tasks at the very beginning of the course, allowed to proceed through approximately six weeks of the course, and then surveyed again at the end of the term to observe how well they had learned the material that the syllabus said they should.

The graphs of the acquired data (in the form of graphs) can be found in the Results portion of this paper (section 4.1), with a general analysis of the trends found in section 5.1. This information can be used not only to ensure that outcomes are being met, but also to locate weaknesses within the program, and suggest ways to go about improving them.

6 Future Work

Due to the three term time constraint of this project not all desired research was able to be completed. Further work could include a variety of options. The RBE 3002 class was not running during B or C term, which prevented us from being able to distribute a before and after survey. Since the class is running in D term, we have created a survey that could be given in the same way that the other Unified RBE surveys were given. A simple graphing of the responses would yield useful data for observations about the quality of the 3002 course.

If not enough continuous improvement is being made with the help from all the results of this IQP study, there are deeper ways to analyze our data. Each of the students majoring in RBE chooses an area of focus in which they are required to take more classes related to that subject. Their choices are limited to computer science, electrical engineering, or mechanical engineering. This means that each student is more likely to have stronger background knowledge in one area while taking a robotics course. If attempts to improve the weak aspects of the robotics courses do not seem to be working, it should be considered that the people who stated they were confident in these areas might have gotten this confidence from the courses in their area of focus. Ways to deal with this difference could be researched.

7   References

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8 Appendix

8.1 Appendix A: Sorted Educational Objectives

achieve ==professional success== due to their mastery of Computer Science theory and practice;

Broad preparation for their ==professional== and personal lives, providing the basis for ***effective professional*** *and civic* ==**leadership**== *and* ***informed citizenship***,

become ==leaders== in business, academia, and society due to a broad preparation in ==mathematics, science & engineering==, communication, ==teamwork==, and social issues;

A graduate should be able to apply the ==fundamental principles== of ==mathematics, science, and engineering== to solve structured problems in mechanical engineering.

An education which is strong both in the ==***fundamentals***== and in ***state-of-the-art knowledge***,

==use their understanding of the impact of technology on society for the benefit of humankind.==

==A graduate should demonstrate the ability to design and develop useful products, processes, or systems that benefit society.==

==An understanding of the broad social and ethical implications of their work.==

==Preparation for immediate professional practice as well as graduate study and lifelong learning==,

==pursue lifelong learning and continuing professional development;==

Strength in all forms of technical and nontechnical communication,

A graduate should demonstrate communications skills, write, oral, electronic and graphical, so that they can perform engineering functions effectively.

==The ability for *effective teamwork*==,

A graduate should develop interpersonal skills, ethical behavior, a professional attitude and a respect for others to function effectively in a ==team environment.==

A graduate should be able to combine fundamental knowledge of engineering principles and modern techniques to solve realistic, unstructured problems that arise in mechanical engineering.

8.2   Appendix B: Surveys

Survey Questions: RBE 1001

   Circle the classes that you have taken:

   RBE 1001   RBE 2001   RBE 2002   RBE 3001   RBE 3002

Scale (Questions 1-7):

   1   2   3   4   5   6   7

Not Confident   Very Confident

How confidently do you feel that you could:

1. Design the electrical component of a robot to meet a specific objective: _____
2. Design the control component of a robot to meet a specific objective: _____
3. Design the software component of a robot to meet a specific objective: _____
4. Design the mechanical component of a robot to meet a specific objective: _____

5. When working in a team, what percent of the time were you doing:
    a. Lab Report: _____
    b. Mechanical Design: _____
    c. Programming: _____
    d. Electrical Design: _____

6. What percent of the work did you and your partners do:
    a. You: _____
    b. Partner 1:   _____
    c. Partner 2 (if applicable):   _____

Survey Questions: RBE 2001

Circle the classes that you have taken:

RBE 1001   RBE 2001   RBE 2002   RBE 3001   RBE 3002

Scale (Questions 1-7):

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |

Not Confident   Very Confident

How confidently do you feel that you could:

1. Formulate one of the following in a simple mechanism:
   a. Position: _____
   b. Velocity: _____
   c. Acceleration: _____
2. Determine power system requirements using force analysis: _____
3. Determine structural requirements using force analysis: _____
4. Specify DC motor requirements for a robot: _____
5. Write moderately involved programs in C for a robot: _____
6. Create an electrical system to convert battery energy into a signal to drive a DC motor:

               _____

7.   a. Construct a mobile robotic system to perform a specified task: _____
      b. Program a mobile robotic system to perform a specified task: _____
      c. Test the operation of a mobile robotic system to perform a specified task: _____
      d. Wire a robot (ECE component):   _____

8. When working in a team, what percent of the time were you doing:
   a. Lab Report: _____
   b. Mechanical Design: _____
   c. Programming: _____
   d. Electrical Design: _____

9. What percent of the work did you and your partners do:
   a. You: _____
   b. Partner 1:   _____
   c. Partner 2 (if applicable):   _____

Survey Questions: RBE 2002

Circle the classes that you have taken:

RBE 1001   RBE 2001   RBE 2002   RBE 3001   RBE 3002

Scale (Questions 1-7):

1   2   3   4   5   6   7

Not Confident   Very Confident

How confidently do you feel that you could:

1. Apply concepts of stress and strain as related to force in robotics applications: _____
2. Analyze sensor signals for signal conditioning: _____
3. Design electronic circuits for signal conditioning: _____
4. Implement algorithms for signal conditioning: _____

5. Write moderately involved programs in C for a robot: _____
6. Create an electrical system to convert battery energy into a signal to drive a DC motor:
    _____

7. a. Construct a mobile robotic system to perform a specified task: _____
    b. Program a mobile robotic system to perform a specified task: _____
    c. Test the operation of a mobile robotic system to perform a specified task: _____
    d. Wire a robot (ECE component):   _____

8. When working in a team, what percent of the time were you doing:
    a. Lab Report: _____
    b. Mechanical Design: _____
    c. Programming: _____
    d. Electrical Design: _____

9. What percent of the work did you and your partners do:
    a. You: _____
    b. Partner 1:   _____
    c. Partner 2 (if applicable):   _____

Survey Questions: RBE 3001

Circle the classes that you have taken:

RBE 1001   RBE 2001   RBE 2002   RBE 3001   RBE 3002

Scale (Questions 1-7):

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |

Not Confident   Very Confident

How confidently do you feel that you could:

1. Demonstrate knowledge of different types of actuators used in robotic systems: _____
2. Analyze the following kinematics of a robot arm in 2D:
     a. Position: _____
     b. Velocity: _____
3. Analyze the dynamics of a robot arm in 2D: _____
4. Analyze sensor signals to implement real-time control algorithms: _____
5. Demonstrate knowledge of error propagation in electrical systems: _____
6. Demonstrate knowledge of error propagation in mechanical systems: _____
7. Demonstrate knowledge of error propagation in computational systems: _____

8. Write moderately involved programs in C for a robot: _____
9. Create an electrical system to convert battery energy into a signal to drive a DC motor:

                                                                                     _____

10. a. Construct a mobile robotic system to perform a specified task: _____
    b. Program a mobile robotic system to perform a specified task: _____
    c.   Test the operation of a mobile robotic system to perform a specified task: _____
    d. Wire a robot (ECE component):   _____

11. When working in a team, what percent of the time were you doing:
    a. Lab Report: _____
    b. Mechanical Design: _____
    c. Programming: _____
    d. Electrical Design: _____

12. What percent of the work did you and your partners do:
    a. You: _____
    b. Partner 1:   _____
    c. Partner 2 (if applicable):   _____

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Survey Questions: RBE 3002

Circle the classes that you have taken:

RBE 1001   RBE 2001   RBE 2002   RBE 3001   RBE 3002

Scale (Questions 1-7):

1   2   3   4   5   6   7

Not Confident   Very Confident

How confidently do you feel that you could:

1. Compute mobile kinematics of a robot: _____
2. Develop a model for mobile robot platform dynamics: _____
3. Implement navigation algorithms based on sensor combinations and environmental
   representations: _____
4. Write moderately involved programs in C++ for a robot: _____
5. Create an electrical system to convert battery energy into a signal to drive a DC motor:
                                                                            _____
6.   a. Construct a mobile robotic system to perform a specified task: _____
      b. Program a mobile robotic system to perform a specified task: _____
      c. Test the operation of a mobile robotic system to perform a specified task: _____
      d. Wire a robot (ECE component):   _____

7. When working in a team in RBE 3002, what percent of the time were you doing:
   a. Lab Report: _____
   b. Mechanical Design: _____
   c. Programming: _____
   d. Electrical Design: _____

8. What percent of the work did you and your partners do in RBE 3002:
   a. You: _____
   b. Partner 1:   _____
   c. Partner 2 (if applicable): _____