

# RBE 2001 Curriculum Review

An Interactive Qualifying Project Report  
submitted to the Faculty of the  
WORCESTER POLYTECHNIC INSTITUTE



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## **I. Abstract**

The RBE curriculum has been known to be particularly rigorous, with RBE 2001 being regarded as one of the more difficult courses. This project's objective was to make suggestions to the curriculum review committee to aid in reducing the difficulty of the course while maintaining the amount of information that students learn as a result of taking the course. Key issues were identified based on surveys, course evaluations, and interviews. These interviews were conducted on students, teaching assistants, student assistants, and professors associated with the course. As a result of the aforementioned methods, it became apparent that the labs, final project, and reference materials were the crux of the issue. This project created suggestions for lab improvements, a new final project, and additional materials to aid students with use of lab equipment and key concepts that are difficult to understand.

## **Acknowledgements**

The authors of this paper would like to acknowledge the great deal of time and guidance that the Staff and Faculty of the RBE 2001 course gave to this IQP. Specifically Nicholas Bertozzi, Bradley Miller, and Kevin Harrington for all the time they spent discussing the intricacies of the project with us. We would also like to thank the student course staff and the students whom we interviewed for their time and valuable feedback which guided the direction of this IQP.

## **II. Executive Summary**

The RBE Program at WPI started in 2007 and has transitioned from graduating only four bachelors students in 2009 to graduating fifty-six bachelors students in 2016 (Coakley, 2017; WPI, 2016). Three years after its founding in September of 2011, the RBE Program gained ABET accreditation that retroactively covered the program from October of 2009 (WPI, 2011). The RBE Program itself is composed of five primary courses called the unified series: RBE 2001, RBE 2002, RBE 3001, and RBE 3002. As the title of our paper implies, we will be focusing on the first course in the unified series: RBE 2001, Unified Robotics I: Actuation.

When making recommendations about how to improve a course, it is important to understand the educational objectives of both the course and its parent program. We will know we have been successful if the recommendations we make strengthen the alignment between the course objectives and student experience. From the course documentation, the primary topics addressed in the course include:

- Conversion of electrical power to mechanical power
- Power transmission for purposes of locomotion
- Payload manipulation and delivery
- Physics/Mechanical Engineering concepts of energy, power, kinematics, statics, simple dynamics, force, moments, and friction
- Power system requirements
- Structural requirements
- Power control and modulation methods
- Programming of embedded processors

### ***Curriculum Design***

In order to establish a set of criteria on which a curriculum can be judged, we looked to other expert sources such as curriculum guidelines from other colleges and publication on course design. An important part of any course is understanding what knowledge the students possess before starting to learn the material covered in the class. As explained by C.M. University (2016):

New knowledge is built on existing knowledge. Thus, when you are planning a class it is important to determine what your students are likely to know coming into your course and (later in the planning process) how well they know it.

Prior knowledge is important because if material is taught too far beyond students' existing knowledge, they will fail to succeed because of lacking the necessary building blocks. However, it is also important to not teach material students are already familiar with too closely. Thus, the provision of supplemental materials that can be accessed by the students who need them can be very helpful.

### ***Methodology***

This IQP began with a survey of the students who had just completed RBE 2001 during the A17 term; this survey was designed to establish a baseline to help determine where the flaws in the course were most apparent from the perspective of the students who had just finished the course in its entirety. The course itself has two parts: the lecture where new materials are introduced and the labs where material is reinforced with hands-on application. These two aspects of the course both culminate in a final test of the students abilities, for the lectures it is the final exam and for the labs it is the final project. To ensure proper evaluation of the courses two facets, students were asked how they felt each of the course's teaching methods prepared them for each of the two final assessments. Additionally, we asked questions about the topics in the course that students felt were unnecessary as well as what students felt they should have been taught but were not; these questions helped to establish where specific changes could be made to help ensure that lecture and lab time is filled with the most relevant information.

In addition to the aforementioned survey, students regularly fill out standardized end-of-course evaluations at WPI. Professor Bertozzi provided us with course evaluations from C17 and A17 so that we could look through them for insights about the course from the student's perspective.

In order to obtain more in-depth information, we interviewed students who had previously taken the course, the lab manager, SAs, TAs, and instructors who currently are and have recently taught the course. These surveys provided insight into the different perspectives within the course and helped us to determine where there were possible discrepancies between them, and will also be a very useful resource for the upcoming summer review. To acquire information about these perspectives we utilized aspects from both SWOT and SOAR analysis methods in combination with more targeted questions into the individual aspects of RBE 2001 that each interviewee would encounter.

### ***Findings and Results***

In general, the interviews all generally supported each other. Each interview often covered a majority of the problems we found in the class. For students, the main interview theme was the course's excessive difficulty, difficulty of learning how to use the lab equipment, or a lack of cohesion between the final project and the labs. Some students also commented on how difficult each lab was. Overall, however, students thought the class contained too much content and also was too difficult for many students. The Student Assistant/Teaching Assistant interviews contained many of the same conclusions as the student interviews, with some added perspective as course staff. The view expressed by the SA/TA group was that the labs and the final project were in need of a stronger connection due to the lack of cohesion between the two sections of the course. Each SA/TA noted that students often were unable to finish integrating the working parts of their robots into one successful package. Many of the assistants described the Computer Science portion of the class as the main

obstacle that students encounter as they work to finish the final project, and as part of it, the Bluetooth module and final project Bluetooth library. Furthermore, the assistants also pointed out the disconnect between the course title, “Actuation” and the course content. While the Computer Science portion of the class is very difficult, the Mechanical Engineering portion of the class is too easy, a view that is reflected mostly in the course staff, including Professor Bertozzi. One main problem in the course is the amount of work each student is required to perform to complete the class, and students and SAs/TAs agreed that having students learn certain software packages such as Algodoo or LabView might cost more time than it is worth. Furthermore, students and SAs/TAs frequently commented on difficulty with hardware as a significant issue. Professor Bertozzi, Professor Miller, and Lab Manager Kevin Harrington were also individually interviewed. Each interview was unique and helped us understand the viewpoint of the course staff from a in-depth position. In general, Professor Bertozzi focused on course theory, Professor Miller focused on Computer Science, and Kevin Harrington focused on future lab improvements. In the upcoming summer review, understanding the perspective of students, student course staff, and faculty will all be important in reworking the class curriculum and will provide a clear look at the course’s problems from an outside perspective.

In order to aid student learning in the class three pieces of supplemental material were created. The first of which was a tutorial on how to use the oscilloscopes in the lab. The second was an introduction to object oriented programming. The third was a PDF detailing the operation of the function generators in the RBE lab. These topics were chosen because our interview process indicated these were areas where students were struggling and there was not a lot of existing material in the class to cover them. The video format was selected for the oscilloscope and object oriented programming topics because while some students may need help in these topics, many come in with lot of previous knowledge on them, thus students who need the additional help can choose to watch the videos. A PDF document was created for the function generator because after review of the device and its functionality we determined that a simple document that allowed students to quickly glance at the information that is relevant to their specific use case would allow the user to obtain the relevant information without having to watch an entire video.

In order to evaluate the labs we created the Lab Evaluation Chart that ranks all of the current aspects of the existing labs as well as possible components that could be added in the future. The Lab Evaluation Chart is designed to act as an aid to faculty when deciding which specific aspects of labs could be updated or replaced in the future. It also considers and ranks recommended new lab components that would be useful for students to have experience with. Part of our goal with the Lab Evaluation Chart was to also evaluate the Mechanical Engineering focus of the labs so that any potential lab aspects relevant to actuation/Mechanism design could be incorporated into an existing lab in place of other aspects that have less educational value. We chose to make a chart with all of the

individual lab components instead of evaluating each lab individually to ensure no aspects would be overlooked or seen as of greater educational value than they truly are as a result of being viewed as part of an individual lab instead as part of the greater lab curriculum.

### ***Final Project***

As a result of our surveys, interviews, and conversations with the course staff; a need for an updated final project for the course was established. There were many contributing factors to this decision the largest ones being:

- Students know what designs work by looking to the past and build proven robot designs every year.
- The current final project is very Computer Science (CS) heavy and not very Mechanical Engineering (ME) heavy in terms of difficulty.
- The current theme for the final project of nuclear rod replacement is outdated as robots in the real-world robots are not used for this application and not likely to be used for it in the future. There exist alternative themes that are more in line with developing fields of robotics.

When working on the design of the new field the difficulty of the challenge in terms of CS and ME was taken into serious consideration. The reasoning behind this being that currently students struggle a lot with the Bluetooth communication, keeping accurate track of the robot's state in the field (where it is and where it is going), and general understanding and execution of object oriented programming concepts. All of these topics, while very important, are not intended to be the main challenge of this course as *RBE 2001: Actuation* is intended to have a focus on ME concepts relating to actuation such as four bar design and analysis.

The theme that we selected for our recommendation was that of a 'Warehouse Robotics' type challenge, similar in style to the solutions that companies such as Amazon Robotics (formerly Kiva Systems), Symbotics, Ocado, and others use today. This recommendation was suggested to us by Kevin Harrington, the lead Lab Manager, and aims at updating the challenge to have a more modern feel analogous to some of the most successful robotics solutions in the market today.

Our recommendation for the new final project for RBE 2001 is contained in *Appendix J: New Final Project Description*. A brief overview of the project is as follows: each team of students is required to make at least one robot to complete the challenge, robots are required to retrieve objects from the Pick Up location, pass through a Gate, place the object retrieved from Pick Up into a Storage Slot in Long Term Storage, retrieve an object from Long Term Storage, pass back through the Gate,

and finally place the object in the Drop Off location. This emulates a robot having to move objects into and out of storage in a storage warehouse.

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Conclusions and Recommendations: Created Materials	All	All
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Appendix	All	All
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## 1 - Introduction

The goal of this project, *the RBE 2001 Curriculum Review Interactive Qualifying Project (IQP)*, was to examine the curriculum of RBE 2001 and suggest revisions. The RBE 2001 Curriculum Review team includes three students in their junior year of the Robotics Engineering (RBE) Program. The motivation for this project is to contribute to the ongoing development of the Robotics Program by suggesting revisions to the curriculum not only based on the educational requirements of the RBE Program but also based on the experiences of students that have taken RBE 2001. The primary way we have addressed the goal is by suggesting ways to restructure existing materials and to provide supplemental materials. Both the restructure of existing materials and the provision of additional materials was undertaken in order to improve the learning efficiency of the course. As a result of our investigation we created two supplemental video guides, a function generator guide, a design and documentation for a new final project, and made various recommendations for improving the labs as well as the CDR and PDR process.

The suggestions that are made are based on interviews with faculty, staff, and students of RBE 2001 and on a survey of students who recently completed the course. How these data were interpreted was aided by our background research relating to how such a program should be taught in order to be successful. The specific improvements this IQP aims to achieve can be broken down into two categories. Improvements to existing course material and creation of new course materials.

The goals for improvement of existing material are:

- Restructuring labs so that they do a better job of preparing students for the final project by working on it incrementally in lab.
- Making modifications to the existing labs to eliminate common points of confusion.

The goals for creation of new materials are:

- Creating a detailed plan for a new final project so that it meets similar design constraints of transporting objects to specified locations but eliminates common frustrations with the complexity of the challenge.
- Creating supplemental videos to aid students who need help with topics that are useful to know but outside the scope of lectures.

The content of these materials has been informed by our surveys, interviews, and background research in order to provide the best possible content. The end result of this project should influence and help improve the structure and curriculum of RBE 2001.

## 2 - Background and Literature Review

### 2.1 - History of RBE 2001

The RBE Program at WPI started in 2007 and has transitioned from graduating only four bachelors students in 2009 to graduating fifty-six bachelors students in 2016 (Coakley, 2017; WPI, 2016). Three years after its founding in September of 2011, the RBE Program gained ABET accreditation that retroactively covered the program from October of 2009 (WPI, 2011). The RBE Program itself is composed of five primary courses called the unified series: RBE 2001, RBE 2002, RBE 3001, and RBE 3002. As the title of our paper implies, we will be focusing on the first course in the Unified Series: RBE 2001, Unified Robotics I: Actuation. This course is accompanied by a series of labs covering linkage synthesis and control that culminate in a final project that requires students to design, fabricate, and program a robot that can navigate a mock nuclear reactor to replace spent fuel rods. Throughout the term that students are taking RBE 2001, they are required to participate in a pair of design reviews, the Preliminary Design Review (PDR) and the Critical Design Review (CDR). The PDR is scheduled towards the middle of the term (usually on the same day as the third lab of the term) so that the review may prompt the students to begin the design process and to catch any early mistakes that the students may be making. Whereas the CDR is scheduled for much later in the term (usually on the same day as the fifth lab) to check in on the teams of students to make sure they are on schedule to complete their projects on time and to make sure they have not overlooked any design issues with their robots.

When making recommendations about how to improve a course it is important to understand the educational objectives of both the course and its parent program. We will know we have been successful if the recommendations we make strengthen the alignment between the course objectives and student experience. In *Appendix A: Program Objectives* and *Appendix B: Course Description*, complete documentation defining the content and objectives of the course is provided. From the course documentation, the primary topics addressed in the course include:

- Conversion of electrical power to mechanical power

- Power transmission for purposes of locomotion
- Payload manipulation and delivery
- Physics/Mechanical Engineering concepts of energy, power, kinematics, statics, simple dynamics, force, moments, and friction
- Power system requirements
- Structural requirements
- Power control and modulation methods
- Programming of embedded processors

The majority of the concepts outlined in the course documentation are related most directly to mechanical engineering. For this reason, much of our IQP will focus on developing the mechanical aspect of the course; however, as currently taught, the course has the reputation of being very difficult because of the dependence on computer science concepts. In other words, there is a mismatch between the stated objectives of the course and the most difficult topic in the class. As stated by Professor Bertozzi when asked about what parts of the course students struggle with, “Well I think probably the biggest problem is students getting all of the software integrated to work as one complete unit” (Prof. Bertozzi Interview, 2/8/2018). Two possible ways to try and alleviate this problem are to decrease the difficulty of Computer Science activities in the course and to provide supplemental educational resources to aid students who are having difficulty with Computer Science. However, it is still important for the course to maintain aspects from all three of the subfields of robotics (Mechanical Engineering, Electrical Engineering, and Computer Science) as stated in the mission statement of the RBE program “No single discipline provides the breadth demanded by robotics in the future.” (WPI COURSE CATALOG (2017-18), pg. 121). WPI and all educational institutions teaching robotics should continue to appropriately represent these three disciplines in order to make well-rounded robotics engineers.

## 2.2 - Curriculum Design Research

In order to establish a set of criteria on which a curriculum can be judged, we looked to other expert sources such as curriculum guidelines from other colleges and publication on course design. An important part of any course is understanding what knowledge the students possess before starting to learn the material covered in the class. As explained by C.M. University (2016):

New knowledge is built on existing knowledge. Thus, when you are planning a class it is important to determine what your students are likely to know coming into your course and (later in the planning process) how well they know it.

Prior knowledge is important because if material is taught too far beyond students' existing knowledge, they will fail to succeed because of lacking the necessary building blocks. However, it is also important to not teach too close to what the students already know as they will not gain new knowledge and may become apathetic and bored causing them to miss future important material. Finding the best balance can be a very difficult, especially in the Robotics Engineering program, as students come in with diverse backgrounds. While other courses may be able to perform pre-tests to determine student ability and thus tailor the difficulty of the course to the needs of the students, the fast pace of the RBE curriculum may not always allow for teaching or review of foundational concepts that only some students are lacking knowledge in to be taught in lab or lecture. Thus, the provision of supplemental materials that can be accessed by the students who need them can be very helpful.

One of the main objectives of the RBE program at WPI is to have students develop effective team working skills. The WPI Course Catalog (2016) states that students who graduate are expected to have, "...an ability to function on multi-disciplinary teams [and] exert technical leadership over multi-disciplinary projects and teams." (Worcester Polytechnic Institute, 2016, p. 121. The emphasis on team building is also an important aspect of other robotics programs. According to C.M. University (2016):

If developing teamwork skills is one of your learning objectives for the course, it's important to assess students' progress toward that goal. In other words, you should assess process (how students work) as well as product (the work they produce).

Following this guideline, in order to have effective development of team working skills, the course should evaluate not only the sum total of the final project but also evaluate how well the team made progress and met their smaller goals along the way to their final product. Because it can be difficult for a professor to peer into the dynamics of a group, methods such as peer evaluations and self-evaluations are recommended by C.M. University (2016). Other methods such as design reviews may also be useful. Such evaluations should be used to help inform professor feedback and student grades. When being used to affect student grades a clear rubric should be presented to the students.

Another important aspect of any curriculum is ensuring that the material builds in complexity by starting with simple pieces and then eventually integrating them together. Such curriculum design allows students to grasp simpler concepts and link them together near the end of the course into something more complex that would have been too difficult to teach outright. As Fink (2003) argues, "The goal is to sequence the topics so that they build on one another in a way that allows students to integrate each new idea, topic, or theme with the preceding ones as the course proceeds" (p. 128). This philosophy and structure for curriculum design fits the needs of the robotics classes at WPI very well as the final projects can be very overwhelming, thus breaking down the final project and having concrete goals and materials of it included in the preceding labs can help students stay on track. This

sentiment is also supported by the SAs who help and teach the RBE 2001 students many of the lab concepts. As stated in an interview:

Generally I feel that the course is too dense with content and requires too much of students. It is not cohesively structured such that you develop off of existing knowledge.  
(SA Interview #4 - 1/29/2018)

To summarize, based on our research into curriculum design and our interviews with the SAs several recommendations can be made about the course. First, there is consensus in our findings that it is important to have the final project be well supported by cohesive labs which aim to help students make progress on the final product along the way. Secondly, it is important to evaluate not just the final product but also the process which the students use to get there. Evaluating the process can be difficult, but ensures students take the actual engineering process and teamwork seriously. As stated by Ohlad when writing about Purdue's CATME software, "we should do more than just 'use' teams in the classroom: We should leverage them as a context within which to teach about teams and teamwork" (Ohlad, 2012). The use of team creating and evaluating software such as CATME could provide valuable insight into how well teams are functioning so that the teamwork aspect of the class could be better evaluated. Furthermore, if students take the process more seriously it can prevent falling behind near the end of the term. For this reason, we find it advisable to evaluate the CDR and PDR process, a topic that will be discussed further in our findings. Additionally the useful potential use of team evaluation software will be discussed.

### 2.3 - Past Projects

To gain further understanding of important things to consider when revising elements of a curriculum we researched similar projects, such as IQPs and MQPs. This research helped us inform our decisions when designing our methodology by showing us where similar projects excelled and considering what made them successful. Not all of the IQPs we looked at are included here, but the most relevant projects are included instead.

#### Overview

Multiple IQPs in the past have focused on creating course materials for the robotics sequence. In 2013, an IQP created a chapter of an electronic textbook for use in the introductory robotics class, RBE 1001. In 2015, an MQP was created to create additional chapters of the textbook, expanding on the work of the original IQP. After the conclusion of the MQP, another IQP was then created to evaluate



the impact of the created textbook, using the limited chapters created. The evaluation IQP noted that professors and students perceived a lack of rigor and accuracy in the content of the book and the textbook was eventually abandoned.

In the year 2016, a new IQP, “Robotics Curriculum Enhancement”, was undertaken to develop course materials for the entire RBE sequence, with the hope that they could provide more useful, higher-quality resources that would more effectively scaffold learning throughout the robotics course series (10/13/2016). Due to differences in teaching style, the videos are not currently used in class.

Further back in time, an IQP, “Analyzing the Accreditation Venture of the Undergraduate Robotics Engineering Program”, submitted on 3/3/10 was created in order to assess the robotics program readiness for ABET accreditation before it went under review later in 2010. To ensure that the program would be ready, the IQP made recommendations for specific improvements to the program and to make the program conform more closely to the ABET guidelines. In 2010, WPI received accreditation for its robotics program, and in 2016, the program won ABET’s Innovation award for the creation of the first accredited robotics engineering program. This award has provided WPI an amazing opportunity to showcase its innovative robotics program.

#### RBE 1001 Textbook Projects

WPI’s robotics program is very innovative, breaking new ground by being the first to create an accredited undergraduate degree. The downside of such a cutting-edge program is that very few resources exist online when compared to more traditional programs such as Mechanical Engineering or Computer Science. In order to create additional materials, which would aid in the teaching of the class, an IQP in 2013 set out to create a textbook for the Robotics Engineering Program. This IQP was named “Designing and Evaluating an Interactive eTextbook for RBE 1001” (5/23/2013). The focus of this IQP was placed on developing resources to create an inverted classroom environment and to introduce that learning style to the course with the hope that it would reduce the amount of hours the professor spends lecturing while boosting learning efficiency. An inverted learning environment allows professors to reduce the amount of class time spent on lectures, encourages students to master the material on their own time, and both professors and students to spend time practicing and applying concepts in class where the professor is available to assist. While Professor Stafford uses inverted learning in his introductory class, and it is relatively successful in controlling lecture time for that course, the project “quickly fell behind schedule”, leaving a “miniscule amount of material for the study to use” (“Designing and Evaluating an Interactive eTextbook for RBE 1001,” 5/23/2013). The project became inactive for a few years but left behind a framework that would ultimately be taken up by a new team.

In order to improve upon the textbook design created in the eTextbook IQP, two additional projects were undertaken: an MQP entitled “Creating an Electronic Textbook: A New Resource for WPI’s Introduction to Robotics Course” and a related IQP entitled “Effects of Electronic Textbooks on an Introductory College Course”. Five more chapters of the textbook were written by the end of the MQP; however, the MQP team stated in their report that “a completed e-textbook for this course should have around 25 chapters”, estimated by “looking at the syllabus and picking out all of the major topics” (“Creating an Electronic Textbook: A New Resource for WPI’s Introduction to Robotics Course,” 3/23/2015). In the three years since the project, no more projects were created to further develop the textbook, leaving it once again effectively abandoned. From these two projects, we can learn that it is important for resources to remain relevant and be promoted by the teacher if a video should continue to succeed.

Multiple sections of RBE 1001 were tested with the textbook during the evaluation, with Professors Gennert, Stafford, and Putnam. However, even during the evaluation, “views and book usage were extremely low” (“Effects of Electronic Textbooks on an Introductory College Course,” 4/22/2015). One reason this likely happened was the professors did not want to tell students to use the current version of the textbook. One professor said they “believed it wouldn’t be appropriate to require any readings from an incomplete book” (“Effects of Electronic Textbooks on an Introductory College Course,” 4/22/2015). However, even in sections where the professors required its use with a clicker quiz using book material, Prof. Stafford noted that “test scores are not significantly different” and that the textbook is “not a substitute for lectures” (“Effects of Electronic Textbooks on an Introductory College Course,” 4/22/2015). We can conclude that balancing the depth of the information provided in the textbook with its readability is very delicate. Too dense, and students will have a difficult time understanding the material, and too sparse, and the material will be even less useful than the lectures. Prof. Gennert somewhat disliked the content of the textbook, noting that it “contains student misperceptions” (“Effects of Electronic Textbooks on an Introductory College Course,” 4/22/2015), and “some of the material was incorrect or imprecise” (“Effects of Electronic Textbooks on an Introductory College Course,” 4/22/2015). These comments alerted us to the fact that we must be careful with the content of our supplemental materials, as they will be discarded if any sections are perceived as inaccurate or misleading. Because of the lack of high confidence in the content and the low usage by students, the textbook projects were not fully successful in their attempts to provide useful course resources. To provide successful content, we must be careful to ensure the video conforms to the course professor’s preferred teaching approach, to ensure it continues to be used.

Noting that the previous groups were unable to complete their goal for chapters, the new group made some key decisions in order to decrease their work to learning ratio to help improve their chances of creating a successful textbook. Primarily, they decided to focus specifically on gaps in the knowledge of the current course sequence, in order to provide resources that students would find useful and not redundant, in comparison with the previous IQPs. Secondly, they carefully selected the type of media that they would develop, deciding that video would be the best form for the information. Some of the lectures were recorded with professors from the robotics department to address the concern that the videos would be viewed as inaccurate or not rigorous enough, similarly to how the RBE 1001 textbook has been evaluated. The professors could be viewed as a trusted source of information, and were allowed some leeway into the content of their video lecture, reducing the risk of a conflict of opinion between professors over the best way to describe a concept. To record the videos, different professors were given scripts on various topics covered by the course, such as mechanisms, and were allowed to alter the scripts to their liking. However, some sections of the videos currently are unused due to differing perspectives on the content included. One section of videos was recorded without a professor, but this section's subject was a basic tutorial on lab equipment, which is a notably simpler topic than the theory of the other videos. Unfortunately, the material has received less use than desired, and the course still has room for improvement, which we hope to address with this project.

#### Analyzing the Accreditation Venture of the Undergraduate Robotics Engineering Program

When WPI first created the robotics program, there were no ABET-accredited robotics programs in the country. This left WPI without a guide in creating a program that conforms well to ABET guidelines. At the time this IQP was formed, WPI's robotics program was scheduled to undergo ABET review for accreditation, and thus WPI was looking to assess and make recommendations for the robotics program to ensure it would receive accreditation, ultimately resulting in this IQP. Each class in the unified sequence was surveyed twice, once at the beginning of the course, and once at the end, on their confidence in key course topics. In the survey for RBE 2001, two questions have particularly interesting results. In question 1C, "How confidently do you think you could formulate the acceleration in a simple mechanism", confidence actually decreased at the end of the class ("Analyzing the Accreditation Venture of the Undergraduate Robotics Program," 3/3/2010). While it is understandable that students might re-evaluate the difficulty of mechanism kinematics following the course, understanding mechanism kinematics is a main learning objective of the course, and students are

reasonably expected to feel more comfortable in this topic by the end of the course. For this reason, changes to the final project to require a higher standard of learning in this area would likely improve student confidence following the course, at the cost of a slightly higher requirement of student learning. The following question, question 2, “How confidently do you think you could determine the power system requirements using force analysis” is focused on dynamic analysis of mechanisms, another central topic in the course (“Analyzing the Accreditation Venture of the Undergraduate Robotics Program,” 3/3/2010). Similar to the previous question, the increase in confidence is markedly lower than the other topics in the course, and improving student understanding in these topic areas is vital to the success of the class in achieving its stated learning outcomes (“Analyzing the Accreditation Venture of the Undergraduate Robotics Program,” 3/3/2010). Increasing the rigor of the mechanical aspect of the final project will require students to more fully understand kinematic and dynamic analysis to complete the course. The revision process for the final project focused on altering the final project to ensure students complete the course with a more thorough understanding. This fuller understanding may result in students becoming more familiar with the course’s projected learning outcomes, as part of the student’s learning objectives.

### 3 - Methodology

#### 3.1 - Planning

To effectively schedule our time, set deadlines for ourselves, and keep track of what sub tasks our IQP team was working on; we created a Gantt chart. This chart is attached in *Appendix C: Gantt Chart* and can be viewed in order to gain a visual understanding of the accomplishments of this IQP.

#### 3.2 - Surveys

##### Preliminary Survey - A17 students

This IQP began with a survey of the students who had just completed RBE 2001 during the A17 term. This survey was designed to establish a baseline to help determine where the flaws in the course were most apparent from the perspective of the students who had just finished the course in its entirety. The course itself has two parts: the lecture where new materials are introduced and the labs where material is reinforced with hands on application. These two aspects of the course both culminate in a final test of the students abilities, for the lectures it is the final exam and for the labs it is the final project. To ensure proper evaluation of the courses two facets, students were asked how they felt each of the courses teaching methods prepared them for each of the two final assessments. Additionally we

asked questions about the topics in the course that students felt were unnecessary as well as what students felt they should have been taught but were not; these questions helped to establish where specific changes could be made to help ensure that lecture and lab time is filled with the most relevant information.

The instrument used to conduct this survey was a Qualtrics survey with five four-option Likert scale questions. The first four were about the extent that various parts of the class prepared students for the two most important grades in the class. The last Likert scale question was about overlap in content with other courses. Lastly, there were four short answer questions about various topics. These methods were chosen to give us a variety of data in order to answer our research questions.

### Results

The response rate was 38% (26/67) which for an online, cold-call survey is a reasonable rate as typical email survey response rates are in the range of 25%-30% according to (Fincham, 2008). The survey response rate was comparable to the response rate for the official end of course evaluations that were handed out to the class by the professor. While 38% participation may seem low, the written responses provide valuable feedback on issues students had with the course. Additionally the patterns of response for the Likert-scale questions (four point, agree/disagree) multiple-choice questions, while not perfectly statistically significant; confirmed our expectations about which aspects of the class prepare the students well for the final exam and final project. In brief the conclusions were:

Table 1: Student Survey Likert-Scale Questions Summary

Question	Summary	Very Affirmative	Affirmative	Negative	Very Negative
To what extent did the lecture material prepare you for the final project?	54% Affirmative (“Very well” or “Well”).	3.85%	50%	38.46%	7.69%
To what extent did the lecture material prepare you for the final exam?	81% Affirmative (“Very well” or “Well”).	38.46%	42.31%	15.38%	3.85%
To what extent did the labs prepare you for the final project?	65% Negative (“Not so well” or “Not at all”).	0%	34.62%	42.31%	23.08%
To what extent did the labs prepare you for the final exam?	81% Negative (“Not so well” or “Not at all”).	3.85%	15.38%	57.69%	23.08%
There is too much overlap with RBE 2001 material and	81% Negative (“Disagree” or	7.69%	11.54%	65.38%	15.38%

material covered in other WPI classes.		“Strongly Disagree”).				
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*For the complete results of the A-Terms survey, see Appendix D: A-Term Survey*

As we expected the multiple choice questions on the relationship between the different sections of the confirmed that the lecture prepared students relatively well for the final exam with 80% of students saying the lectures prepared them well for the final exam. However, in contrast to the theoretical component of the class, the practical component of the class did not receive as good of a review with 65% of students saying the labs did not prepare them well for the final project.

In terms of the written responses, sentiments about the course varied greatly. However, many useful insights into the problems students have with the course can be gained from them. To see the full list of written answers see *Appendix D: A-Term Survey*. There were a total of four short answer questions. The questions and summaries of the responses are as follows:

Question: 1 - What topics do you think should not have been included in this course, and why?

Answer Summary:

In general, students expressed complaints about the large number of different pieces of software that are used in the course. Examples include Algodoo, Norton linkage software, Mathcad. Students expressed a desire to learn programs such as Matlab and Solidworks instead.

Question: 2 - Were there topics that would have helped you complete the course that were not included? If so list examples.

Answer Summary:

Most students who took the survey expressed a desire to learn more Computer Science, or “CS”, concepts in lecture. In general it seems students feel the lecture is very ME heavy while the final project is very CS demanding thus, students feel ill-prepared for the final project. Students expressed a desire to be taught and given examples of how to program a state machine and how to complete a large object oriented projects. A possible solution is the reduce the CS complexity of the final project while at the same time increasing resources for students to learn the CS concepts that they feel they lack. Additionally many students expressed a desire to have the labs build up to the final project so that they are making progress as they complete their lab. Currently students have trouble managing time and end up spending all their time struggling to complete the labs by the deadline and pushing back the final project. If the labs built toward the final project in a more concrete cohesive way like in the 2017 revision of RBE

3001 students would have an easier time with the final project, as they would be forced to make progress that directly can be used in the final product during the labs.

Question: 3 - Would your current knowledge of the robotics program at WPI affect your decision to attend WPI or to be a robotics engineering major? Please explain why.

Answer Summary:

The reason this question was included was to gauge the level of satisfaction/dissatisfaction students have with the RBE program. In recent times, many have noticed a growing level of discontent among the students. With this question we hoped to get a record of some of the complaints so they could be evaluated for their legitimacy and if legitimate, addressed in future improvements of the RBE program. Answers varied greatly but below are key excerpts. For a complete list of the answers, see *Appendix D: A-Term Survey*.

Table 2: Survey Question 3 Short Answer Responses

Knowing what I know now I would...

change my decision to do robotics at WPI:	NOT change my decision to do robotics at WPI:
<p>“...I had to drop all of my hobbies and extracurricular activities and stop spending time with my significant other and friends, just to keep up with the workload, and as finals approached, even that was not enough. I would encourage anyone who enjoys robotics not to major in RBE at wpi.”</p> <p>“Yes. It absolutely would. I liked robotics before coming here, but if I honestly knew the amount of b***** that we are subjected to, and the professors/TAs/SAs just laugh off and say "yeah, that's just the way it is", when I can see clearly that that which we are complaining has a very easy solution...”</p> <p>“I would be more hesitant about becoming a robotics engineering major, because the continuity between labs, lectures, exams, and the final project is a little bit underwhelming, and all expect skills coming into the course not covered by prerequisites or class material.”</p> <p>“I am very passionate about robotics, and I love what I do, but I have a very hard time with the RBE program and it makes it hard for me to continue liking robotics. It is physically and emotionally unhealthy for most people I have seen or talked to, and it has been very bad for the balance of my life. I also wish I had an easier way to voice my concerns about the program and learn about what steps are being taken (or what steps I can take) to improve it.</p>	<p>“I'm glad I went to WPI because the hands on part of the course is vastly different from the lecture portion, as you have to learn how to apply it.”</p> <p>“Nothing could ever stop me choosing to be an RBE major at WPI. That being said ... Please, please, please give us more time to do our projects. We cannot do 15-hour labs each week (which almost never contribute to the knowledge we'll use on the final project) AND work on our final project as much as we need to. The RBE course system is badly broken and needs to be fixed.”</p> <p>“I love the topics and material but workload is excessive”</p> <p>“I would still go here, I love the hands on final project approach to the class”</p> <p>“It would not because robotics is a passion of mine that I want to persue. I would be hesitant to take 2001 because of how difficult it was. It was unnecessarily hard. It could be split into two classes easily.”</p>

That said, I am very grateful for this form.”	
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Question: 4 - Are there any other comments or concerns you would like to tell us about the RBE 2001 course?

Answer Summary:

In general, students expressed a desire to have:

- Labs build up toward the final project in a more cohesive way.
- More lab equipment and labs space/replacement of broken or breaking lab components/equipment.
- Reduced workload. Current lab, homework, and exams take time away from final project.
- More prerequisites

In summary, students overwhelmingly expressed a desire to have the labs more cohesively build up to the final project, with 57% of the answers to this question stating something about how it would be better if the labs incrementally worked on the final project.

### 3.3 - End of Course Evaluations

In addition to the survey we designed for students to take at the end of the term, students regularly fill out standardized end of course evaluations at WPI. Professor Bertozzi provided us with course evaluations from C17 and A17 so that we could look through them for insights about the course from the students' perspective. The complete results of these evaluations are included in *Appendix E: A-Term End of Course Evaluations* as they may provide valuable insights into the course. Summaries of several key responses have been provided below as a sampling of the most recent instances of the course.

First, let us look at the average time spent on the course by students outside of formally scheduled class. In the end of course evaluations, the question is worded as follows:

On average, what were the total hours spent in each 7-day week OUTSIDE of formally scheduled class time in work related to this course (including studying, reading, writing, homework, rehearsal, ect.)?

This data proved difficult to analyze statistically for two reasons. First, the responses included ranges that needed to be averaged. Secondly, the last and most frequent response had no upper bound. By averaging each of the possible responses and approximating the uncapped upper bound as two above the listed number (21+ was assumed to be 23) the following statistics were produced:



- **41.4%** of Students said the course took 21+ hrs/week outside of course formally scheduled class time when averaged across all four data sets.
  - C01 - 17: 33%
  - C02 - 17: 42%
  - A01 - 17: 36%
  - A02 - 17: 53%
  
- **15.7 hours/week** were spent outside of scheduled class time by the average student per week across all four data sets.
  - C01 - 17: 16.61 hrs/week
  - C02 - 17: 17.76 hrs/week
  - A01 - 17: 17.09 hrs/week
  - A02 - 17: 11.33 hrs/week

Students were also asked on a scale of 1-5 (1 being much less and 5 being much more) “The amount of effort I put into this course was:” The results are as follows:

- **4.7/5** Across all sampled terms
  - C01 - 17: 4.6/5
  - C02 - 17: 4.5/5
  - A01 - 17: 4.8/5
  - A02 - 17: 4.9/5

Next, let us take a look at the quality of the course. There are several questions designed to gauge students’ thoughts on the quality of the course in the end of course evaluation. In general, students responded positively to questions about the quality of course that depended on Professor Bertozzi performance as an instructor. Across all related categories most responses usually averaged at approximately a 4 out of 5 (1 being very poor and 5 being excellent). In general, it can be said that most aspects of the course were scored in the range of 3-5 out of 5. Highlights of these ratings can be seen below.

Table 3: End of Course Evaluation - Course/Professor ratings  
(1-5 Scale; 1 = Very Poor/Never/Much Less and 5 = Excellent/Always/Much More)

Question	C01-17	C02-17	A01-17	A02-17	Cross Term Average
My overall rating of the quality of the course is:	4.1	4	3.9	4	4.0
My overall rating of the instructor's teaching is:	4	4	3.9	3.7	3.9
The educational value of the assigned work was:	4.3	4.3	3.9	4.4	4.2
The instructor's skill in providing understandable explanations was:	4.4	3.7	3.7	3.9	3.9
The intellectual challenge presented by the course was:	4.6	4.6	4.9	4.5	4.7
The instructor was well prepared to teach class:	4.4	4.6	4.8	4.5	4.6
The exams and/or evaluations were good measures of the material covered:	4.6	4.3	4.6	4.7	4.6

In contrast, however, this did not hold true for the labs. The labs received the poorest marks in general.



Table 4: End of Course Evaluation - Lab ratings  
(1-5 Scale; 1 = Very Poor/Never/Much Less and 5 = Excellent/Always/Much More)

Question	C01-17	C02-17	A01-17	A02-17	Cross Term Average
Relative to other lab experiences, the intellectual challenge presented by the lab assignments was:	4.6	4.5	4.6	4.4	4.5
The lab and/or computer equipment was in good operating condition:	3.5	2.8	2.5	4	3.2
The instructor showed me how to use lab equipment properly:	3.4	2.7	3.2	3.8	3.3
Relative to other lab experiences, the clarity and specificity of the lab assignment objectives was:	2.6	2.5	2.4	3.3	2.7

For this reason, our IQP focused on ways to improve the labs and final project, as they were the parts of the course that received the lowest ratings from the students during the end of course evaluations. Aspects of the course that received good ratings (such as the lectures and exams) were not considered for major updates as we had evidence that they were performing well.

### 3.4 - Interviews

In order to obtain more in-depth information, we interviewed students who had previously taken the course, the lab manager, SAs, TAs, and instructors who currently are and have recently taught the course. These surveys provided insight into the different perspectives within the course and helped us to determine where there were possible discrepancies between them, and will be a very useful resource for the upcoming summer review. To acquire information about these perspectives we utilized aspects from both SWOT and SOAR analysis methods in combination with more targeted questions into the individual aspects of RBE 2001 that each interviewee would encounter. Each interview was then transcribed for later use, and are included in *Appendix F: Faculty and Staff Interviews*, *Appendix G: Student Assistant Interviews*, and *Appendix H: Student Interviews*.

### Interview Design

To give our interviews a comprehensive structure, we decided to use a common framework to help structure our questions and target them effectively. SWOT and SOAR are strategic planning techniques used to help understand the main problems of an organization, usually used to help make strategic decisions. SWOT stands for Strengths, Weaknesses, Opportunities, and Threats, and is a business-focused approach for assessing the strength of a company. SOAR analysis is similar, but

focuses on improving organizations instead of assessing the market position. For each interviewee, we considered what their relevant knowledge they would have and chose questions that would give us useful information. Too many questions will cause the interviewee to become brief, and result in lower quality answers to each question. The intent of the question design was to get the most amount of information from various perspectives as we could, to allow us to comprehensively understand the problems and successes of the class, while compensating for the small sample size with qualitative, rather than quantitative information.

## Staff

The professors and faculty associated with the course possess insight into the course from an administrative perspective and the perspective of years of experience into the subject, providing information that spans multiple terms of teaching the course. We asked these faculty members questions specific to their office hours; what they thought the student, SA, and TA experience of RBE 2001 was; and questions specific to the lectures, labs, and final project. All staff interview transcripts are available in *Appendix F: Faculty and Staff Interviews*.

### *Professor Nicholas Bertozzi, 2/8/2018*

Professor Nicholas Bertozzi is the primary professor for the RBE 2001 course as of the writing of this paper. He is also the lead advisor for this IQP.

One of Professor Bertozzi's main concerns in the interview was the time commitment the course requires. According to the professor, some students even tell the professor that they had to sacrifice other parts of their school life just to get through the class (2/2/2018). When Professor Bertozzi first came to WPI, he understood the philosophy of the program is to teach students to teach themselves, and collect information independently. The current approach to independent learning is a valuable skill, but can be "too much, at times" (2/2/2018). Unfortunately, the large amount of content in the class causes each lecture to contain too much information for students to absorb. Even after scheduling extra lecture hours as "recitation", there is not enough class time to properly cover each topic. To fix this problem, over the summer, the professor would like to change to a more inverted classroom style, similar to Professor Stafford's class, because, as Professor Bertozzi mentioned, "lecturing people is one of the most inefficient ways possible to learn" (2/2/2018). Giving students more time to learn on their own, and time in class to try out what they have learned will give students the ability to better spend their time, and the professors' time, in a more effective and engaging learning process. Furthermore, if the labs cohesively build towards the final project, students will better be able to

understand the material, in order to apply it to a real problem. The professor did mention that he has been told that currently the amount of material students have to watch outside of class is too much for some students, but he addressed this by saying that they could perhaps condense the material over time (Bertozzi, 2/2/2018). One major concern of Professor Bertozzi was the amount of work each individual lab takes. He also noted that only in robotics labs are students expected to spend countless hours outside the lab (2/2/2018). Part of the reason that this happens is the unreliable lab equipment, most frequently mentioned are the final project field and the Bluetooth modules. He also noted that the Bluetooth is an issue that causes many students problem throughout the course, and ultimately is responsible for some students performing more poorly in the course than they would otherwise (Bertozzi, 2/2/2018). When working with the Bluetooth, the two main issues students face are unreliable hardware and programming inexperience. The result of these two issues is a decrease in student performance and an increase in student frustration, and conclusively an increase in the difficulty of the course. However, if the program moves to a new platform with integrated communication, then this problem will likely be resolved. Moving forward, if a new library is developed, reducing the complexity of programming the field communication for the students should be an important focus, considering the focus of the class. In general, Professor Bertozzi thinks that the difficulty of the programming required for an actuation class is currently too much for students who have little programming experience. Aside from the Bluetooth, integrating code is a problem for many students. Professor Bertozzi estimated that about fifty percent of students struggle with integrating their code for the final project (2/2/2018). Many students write different programs for different parts of the final project, getting components working individually, leading to students putting off integrating until they finish all of the pieces. Often students do not have the necessary programming experience to know how to design code such that it easy to integrate later. When the deadline approaches, students have a lot of difficulty combining their programs, which can sometimes lead to robots only doing some parts of the final project, or even none, another major factor which leads to students performing worse than their effort reflects. In regards to how students perform on the final project, Professor Bertozzi split the students into thirds (2/2/2018). The upper third of students perform exceptionally well, creating robots that exceed expectations, and are very creative. Some of these teams are groups of double majors from each robotics discipline, Mechanical Engineering, Electrical and Computer Engineering, and Computer Science. These teams are able to use their proficiencies in each subject area in order to excel. Often these teams will go the extra mile and purchase special components or even use slave boards (2/2/2018). However, a minor concern of these teams is whether each member gains enough experience in the subject areas that they are less proficient in, but the final exam serves to help ensure that students do learn material from each discipline. The middle third of students create working robots that accomplish the task, albeit with some difficulty (2/2/2018). Often the robots produced by this section of the class do not achieve the

project perfectly, but do perform the majority of the project. The lower third can be grouped into two groups. One group is students who worked hard, and spent a lot of time working on the final project, but were unable to get it working in time, due to a variety of factors such as broken equipment, unexpected difficulties, or bad design (2/2/2018). Some students end up unable to finish simply because they didn't start early enough or poorly estimated the time required to finish the project. Students in this group might try very hard, but just feel overwhelmed. The professor estimates this makes up about four teams per term (2/2/2018). Often the problem with teams like this is due to students not starting the mechanical portion of their robot early enough for them to begin programming their robot. The PDR and CDR process is partially oriented to ensure students begin working on their project early enough. Sometimes, students that would otherwise end up in the top third, instead end up in the bottom third. These students reach too far, and ultimately are unable to complete an ambitious design. Unfortunately, the rubric is "ruthless", and students ultimately are graded on whether their robot is able to perform the final project (2/2/2018). The other group of students, which only make up about a single team each term, are students who simply do not put in enough effort in order to do what is required, and do not put in more effort when it is apparent they will not finish (2/2/2018). Perhaps, some improvements to the way the class is graded could allow students that put in a lot of effort, but ultimately perform poorly, to perform better overall in the class. Some changes in how grades are allocated might allow students to perform better, if their performance on the final project was an outlier. On the final exam, and the other quizzes throughout the course, students perform well overall, which may be an indication of success of the class at achieving its stated learning objectives (Bertozzi, 2/2/2018). Professor Bertozzi attributes this to the review sessions, as they give students a chance to work in an inverted classroom style, allowing them to practice problems in a way that allows them to figure out what they don't understand, as well as giving them the resources to improve in time for the exam (2/2/2018). Because they are successful, little changes are required for the review sessions, but they should be maintained through the future years of the course. The last few points pertain to the program overall. With the summer review in mind, the professor did note that the labs and lab equipment might benefit from an upgrade, considering the rapid development of the field of robotics. The results of this IQP will inform some of the decisions made over the summer, and as a result, new hardware for student lab kits should receive an upgrade. With a lab kit upgrade, students could spend less time working towards getting their lab kits in working order, and more time studying and practicing the material. To keep up with the pace of the robotics field, the professor noted that the program must be dynamic and continually evaluate course topics (Bertozzi, 2/2/2018). As sensor systems become more sophisticated and commonplace, it becomes important to teach students how to integrate high-level components to solve novel and important problems, compared to the current system where students learn some lower level system fundamentals to give students a basis in the underlying

technology. Class and lab time need to balance time spent on fundamentals with applications of current technology (Bertozzi, 2/2/2018). An example that Kevin cited in his interview was stepper motors, often high-torque industrial robots will use brushless motors with high-precision encoders (Harrington, 1/23/2018). As things get higher level and more complicated, it makes more sense for students to understand how to use high-level packages to effectively solve a problem compared to the current system where student spend a lot of time on the lower-level parts that make up the package. It is still important for students to have a good understanding of how these lower level parts work as it gives them the foundational knowledge to design and created more advanced sensors. Overall, Professor Bertozzi feels unhappy with the amount of content the course must cover, as it causes students to not have enough time to fully understand the material (Bertozzi, 2/2/2018).

*Professor Bradley (Brad) Miller*

Professor Brad Miller is the Associate Director of the Robotics Resource Center. For several years he has acted as a guest lecturer for the RBE 1001 and RBE 2001. Professor Miller has many years of experience in computer science and wrote many of the example Arduino programs for the courses such as the current Bluetooth template code.

In Professor Miller's interview, the main topics he focused on were the Bluetooth, the final project, and the lab equipment. He also mentions that the curriculum is currently too full, and that there is not enough time to cover all of the material (Miller, 2/8/2018). This problem was referenced by most interviewees, and is a core problem of the course, but curriculum review for the most part will be left for the upcoming summer review. One thing that Professor Miller mentioned was that students frequently comment about the lack of continuity between each of the labs and final project, another common course complaint (2/8/2018). Furthermore, he mentioned there are not enough learning materials provided for students to learn about all of the topics taught in the course (Miller, 2/8/2018). To address this, some materials will be created over the course of this IQP. Professor Miller believes that some of the lab equipment is becoming outdated, specifically the metal hardware, bolts, screws, and shaft collars, motors, and other lab-kit hardware (2/8/2018). Struggling with lab kit components cuts into student's time to work on labs and projects, further exacerbating the problem of the heavy course load. He believes that students should not have to spend time to get the lab equipment they are given to working order. Professor Miller noticed students commented on how low lab supplies cause a lot of delay for students, sometimes resulting in students performing poorly on their projects (2/8/2018). Another observation of Professor Miller was that often students in RBE 1001 in the final competition would have to share motors in between matches due to shortages, which definitely influenced student efficiency (2/8/2018). To help with this problem, new and updated lab and project materials will help

improve the learning efficiency of the course. One part of the final project that Professor Miller is very fond of is the competitive aspect of the final project. He believes that the competitive nature of the class causes students to excel and achieve more than they would had they been more isolated (2/8/2018). He particularly likes how students are able to think outside the box and make creative solutions to the problems, even ones the instructors and staff had never considered previously, and wants to maintain this philosophy into the new final project (2/8/2018). The new final project design will allow students to create interesting and unique solutions.

### *Lab Manager Kevin Harrington*

Kevin Harrington is the Lab Manager for the Robotics Program at WPI. As Lab Manager, he is responsible for making sure the students have good and functioning lab equipment and generally administering the lab space.

Overall, in Kevin Harrington's interview, he placed a lot of importance on updating the program. Primarily, this is focused on updating the equipment, including the robot architecture and lab equipment, as well as replacing the dilapidated Bluetooth field controller, and ultimately the Bluetooth protocol with it. Large infrastructure improvements are planned for Foise, including possibly a laser cutter and a PCB laser fabricator (Harrington, 1/23/2018). He wants the labs to pivot towards more modern topics, and for the lectures to follow (Harrington, 1/23/2018). To begin with the past, Harrington noted that there wasn't good documentation of the lab parts or their sources and thus he has had a lot of difficulty sourcing parts from multiple reliable sources, making it increasingly harder to replenish lab stock and refurbish old lab equipment. To manage this, Harrington has spent a lot of time working on his inventory, inventory system, documentation, as well as creating an issue tracker for lab equipment to help keep him up-to-date on repairs and work prioritization and planning (Harrington, 1/23/2018). This is only made worse by the ragtag assortment of parts required for the current labs, because over time the "two thousand labs became the dumping ground for 'Oh, they need to know blank'" (Harrington, 1/23/2018). Consequently, each lab has multiple, random, outdated parts to maintain. Student Assistants, who are responsible for assisting the students with labs and the final project, according to Harrington, often voice frustration with the outdated parts, as they are difficult to test and easy to break, but hard to diagnose, leaving students and SAs confused with no way to know whether the problem originated in software or hardware (1/23/2018). To address this frustration, Harrington would like to create unit-testing rigs to purpose-test systems, which should resolve these issues (1/23/2018). In the past, Harrington successfully aided the SAs by creating unit tests for the robotic arms, allowing the entire RBE 3001 system to be tested as one piece, all at once in a single integration test. This gave Student Assistants the ability to troubleshoot and more easily find issues, whilst cutting



down on wasteful time spent on diagnosing hardware. A unit test setup also allows SAs to isolate broken components quickly, and without having to check each pin. With more free time, more students can be assisted, and the rate of progress of the lab will increase significantly. Hoping to reproduce the success of the unit testing project in RBE 3001, he would like every hardware system used in the class to be unit-testable (Harrington, 1/23/2018). Harrington believes that if hardware is expected not to work, then students will not even attempt to try, and will instead do the least they can for the best grade, and move on, worse off (1/23/2018). To modernize the class, Harrington would like to remove hardware that is no longer used by professional roboticists, and switch to newer hardware (1/23/2018). For instance, he notes steppers are mostly used for hobbyist applications, and industrial robots have for a long period used mostly servomotors comprised of a brushless DC motor and high-precision digital encoders with integrated PID systems (1/23/2018). He believes that learning potential could be better allocated than on low-tech, cheap sensors like the flame sensor, and that in the real world, robotics companies use purpose-built electronic sensor systems with digital interfaces such as the Wiimote infrared IR tracker (1/23/2018). Cutting down on lower level technologies will give the curriculum more space to deal with harder problems that are more relevant to the problems robotics engineers are studying today, and give students the corresponding skills in lecture to approach these real world problems with experience. To Harrington, this is a tangible, real improvement to the student value proposition (1/23/2018). He wants the Unified Robotics sequence to be something a student wants to put on their resume, or brag about in an interview (1/23/2018). He thinks our current curriculum could more closely follow a real world design process that includes clear models that help improve student understanding and achievement. Improving student's understanding of the design process is one of Harrington's focuses. To this end, adding large amounts of fabrication power with mass amounts of 3D printers would allow the students to be able to print designed parts on demand (1/23/2018). Harrington aims to buy many 3D printers to create a high-volume printing bank to allow students to create parts on demand at a reasonable rate (1/23/2018). With students fabricating the parts that they design, it gives them real world relevant experience and a concrete objective takeaway system which would be valuable for students in interviews. With new fabrication tools, students could even fabricate their own boards, giving them a rare experience, which is valuable in the job market. To Harrington, undergraduates work on problems, graduates solve problems, and PHDs create new ones. With even higher quality education, and a revamped emphasis on engineering skills, Harrington thinks that our undergraduates will be able to act in a higher capacity, on the level of graduates, which would be a massive value to the students, and consequently, the university (1/23/2018). One problem that Harrington focused on was that in our current final project and labs, low accuracy or reliability of certain pieces of lab equipment cause the student's model to become unreliable or unpredictable, and thus students have a difficult time reporting accurate data that completes the lab objective (1/23/2018). Projects that are more relevant to real world

problems or display certain vital robotics skills would be more likely to become useful tools in a technical interview. This problem specifically is due to the current final project combined with the materials students have available, which Harrington believes is an inaccurate model of real world robots, to the point that it has reduced effectiveness for teaching in a modern engineering context (1/23/2018). As a long term goal for the program, Harrington would like for the program to add more 4000 level classes, possibly more classes in the sequence, and even add a culminating final project class integrating the systems created in the other classes, to add further value to each piece as it becomes part of a real working system (1/23/2018). For the final project, Harrington wants the final project to be focused on a real world problem (1/23/2018). One problem that is extremely common is compact storage systems with automated delivery, and inventory management, according to Harrington (1/23/2018). In fact, Harrington mentioned that he spends a large amount of his time doing that alone (1/23/2018). With this focus in mind for a final project, innovative solutions will inevitably be created. Aside from the obvious value of undergraduate research for the students and the school, even possibly new patentable solutions. Harrington would like to implement these solutions himself, with continuous improvements as students create new, better solutions. The goal is to automate that part of his job, turning his office into a giant vending machine of parts within a compact blueprint (1/23/2018). As students succeed in the final project, realistic constraints could be added, such as size limits corresponding to increasing usable warehouse space, or cost limitations to reduce waste, or adding difficult to manipulate, but reasonable objects like what would be found in the shop's inventory. Harrington has many ideas for the program and is very willing to begin implementing them, and he will be an integral part of the upcoming move to Foise.

#### Student Assistants (SAs) / Teaching Assistants (TAs)

Student Assistants and Teaching Assistants are responsible in aiding the professor in teaching the course, and help guide students through the process of labs and the final project. During office hours, they are responsible for answering students' questions and clarifying concepts which students were unable to understand during lecture. Commonly they will also hold help sessions outside of their office hours, in order to supplement the lecture material, to help students prepare for the exams and ultimately the final project. The SAs and TAs that aid in the teaching and running of RBE 2001 have commonly taken the course previously and are exposed to aspects of the course that professors and faculty may not be aware of. These course aspects include student lab work ethic, common pitfalls the students encounter during labs, and common complaints students have.

We interviewed a total of four current and former SAs and TAs in order to gain a better understanding of the problems students frequently have and to understand what parts of the course the

SAs would like to see improve based on their experiences helping students through the labs and final project. Full transcripts of the interviews can be found in *Appendix G: Student Assistant Interviews*.

In general, several important trends were expressed repeatedly by the SAs. The first and possibly most importantly, all of the interviewed SAs at some point in their interview mentioned that the labs lacked in cohesion and felt like lots of various little things that did not built up toward some greater concept. As stated in an interview, "It is not cohesively structured such that you develop off of existing knowledge." (SA Interview #4, 1/29/2018). It was suggested that a structure similar to that of RBE 1001, RBE 3001, or RBE 3002 classes where the individual labs can be directly applied to your final project and help you stay on track to completing the final project on time could be very beneficial (SA Interview #4, 1/29/2018). Another frequent observation were issues with the final project. Observations made by the SAs about the final project include described the grading rubric as convoluted, noticing a growing trend toward the same robot every year, students frequently failing to integrate all the parts of their robots, and that the bulk of the difficulty lies in the Computer Science/Bluetooth portion of the project. The SAs also noted that students struggle with the lab equipment, especially the oscilloscope and the function generator. This is part of why we decided to focus on those topics for our supplemental materials.

Several SAs mentioned a disconnect between the difficult of the programming component of the course and the main topic of the class (actuation). To fix this the difficulty of the programming could be reduced but also the Mechanical Engineering component of the course could be made more challenging. Specifically, two of the SAs mentioned that the weight of the nylon tube in the final project makes the mechanical calculation and design useless, which was something Prof. Bertozzi also mentioned. A heavier object of the robot to move could make these calculations actually necessary in order to not exceed the torque limitations of the motors being used.

Furthermore, they mentioned extraneous software taking up time whilst not being very useful for students to learn.

"Some of the software like Algodoo and Norton just isn't very good at this point in time ... sure you can use it to model second lab aspects however, I don't think that that's important enough for the final project where most students would prefer to use something else. Some other kind of software. So I think there's too many different sets of software... Spending one fourth of a lab working in some random software is not something that's really memorable coming out of 2001."  
(SA Interview #1, 1/18/2018)

When considering material that could be removed or streamlined in the labs, these pieces of software should be kept in mind.

## Past Students

Students who have recently taken the course are able to communicate what parts of RBE 2001 they liked, disliked, and what aspects of the course helped them toward the final assessments, as they have a full understanding of the class in the context of a regular student. To better gauge student opinion of the labs, lecture, and final project; we asked them a mix of questions from the SWOT analysis process, similar to those asked of the professors and faculty. For complete transcripts of the student interviews, see *Appendix H: Student Interviews*.

The ultimate goal of our project is to improve the efficiency of learning in the RBE 2001 course. To achieve this end the current problems must be thoroughly understood. The first step we took in the process of understanding the problem was to design a survey aimed at understanding which parts of the course most needed improvement. This survey was conducted at the end of the A17 term, giving students who had just taken RBE 2001 a chance to reflect on the entire course, and the parts which they had the most trouble with, which proved to be a valuable information source to indicate the parts of the program which need the most inspection. To gain a more in depth understanding of the problems encountered by students we also conducted in person interviews. These interviews provide valuable insights into the student experience that are difficult to uncover with simple surveys as the interviewer can ask follow up questions to answers the students provide. Three students were interviewed for the purpose of this IQP. While having a greater sampling size would have been desirable, the process of transcribing the interviews is very time consuming. Ultimately, we feel that the qualitative information provided by the students offsets the low sample size.

Several topics repeatedly came up during the students responses to the interview questions. The first student repeatedly mentioned that they were not able to work on the final project earlier in the term because they were too busy just trying to keep up with the lab assignments.

What I disliked about the labs, for one, the set up of having an over looming final project which is overwhelmingly the most important thing about your grades and then sprinkled in with all these labs testing specific things. Really hinders your ability to make that final project,  
(Student Interview #2, 2/8/2018)

This problem is exacerbated by several factors. First and most noticeably, the reliability of lab equipment and parts. Students frequently have Bluetooth modules that simply don't work or lack vital parts in their lab kit as stated in a student interview, "My kit was missing a bunch of parts" (Student Interview #2, 2/8/2018). Furthermore, it can be very difficult to get workspace when the lab is full beyond capacity most days of the week with both RBE 2001 and RBE 3001 students. The space problem will be at least partially alleviated by the addition of Foisie Innovation Studio in Fall 2018. There remains an issue with the time requirements of the course. Students who did well in the course frequently spend "15 to 20 hours to finish [labs]." (Student Interview #3, 2/26/2018) when students spend this much time

on the labs they cannot also be expected to work on the final project early especially when providing for the time requirements of the other two classes they are expected to take per term. A great solution to this issue would be to better integrate the labs with concrete goals for the final project. This way by working on the labs, students are also making progress on the final project. Another important was to reduce this student frustration about labs taking away time from the final project it to make absolutely sure they don't have to spend large amounts of time debugging the provided hardware. When students come across hardware that does not work, they either have to debug it themselves or try to come back into the lab at a time when the lab manager or an SA can provide them with help or a replacement part. This creates long periods of productivity for teams through no fault of their own.

Another point that was brought up by students was that the lectures are very dense with content. This quite simply stems from there being a lot of content currently in the RBE 2001 course.

...most other topics were touched on and not really delved into. And then the really quick turnaround on all the labs to have all that on the tests again. Not quite enough time for practice. (Student Interview #3, 2/26/2018)

...there's no way you can glean most of everything you need from that slide before it goes on and then you have to check the computer to see the slide he pulled up and then you're already behind. (Student Interview #2, 2/8/2018)

However it can be nearly impossible to cut content from the course as almost all the lecture topics are valuable to the final project or the educational objectives of the course. Students generally feel that the difficulty of RBE 2001 is much more than the difficulty of RBE 2002. It may be advisable to shift some content out of RBE 2001 and into RBE 2002.

## 4 - Findings and Results

### 4.1 - Evaluating existing materials:

#### Labs

In order to evaluate the labs we created the Lab Evaluation Chart that ranks all of the current aspects of the existing labs as well as possible components that could be added in the future. The Lab Evaluation Chart in Appendix L: Lab Evaluation Table utilizes the following criterion:

- educational value outside the final project (weight of 1.25)
- relevance to the current final project (weight of 0.75)
- relevance to the new final project (weight of 1.0)
- time consumption in minutes (weight of -0.25)

Brief explanations of the overall scores are also included. The rationale behind the weightings used in the chart is as follows: The educational value of the material is weighted the highest because the goal of the course is to educate students. The current final project relevance has a weight of 0.75 because this IQP is suggesting that the project be replaced. On the other hand, the relevance to the new final project has a weight of 1.0 because lab cohesion toward a final project is an established concern among faculty, SAs, and TAs. Finally, time consumption has a weight of -0.25 because it should negatively affect the composite score and should be scaled down to accommodate for the larger scale of the ratings in that category.

The Lab Evaluation Chart is designed to act as an aid to faculty when deciding which specific aspects of labs could be updated or replaced in the future. It also considers and ranks recommended new lab components that would be useful for students to have experience with. Part of our goal with the Lab Evaluation Chart was to also evaluate the Mechanical Engineering focus of the labs so that any potential lab aspects relevant to actuation/Mechanism design could be incorporated into an existing lab in place of other aspects that have less educational value. We chose to make a chart with all of the individual lab components instead of evaluating each lab individually to ensure no aspects would be overlooked or seen as of greater educational value than they truly are as a result of being viewed as part of an individual lab instead as part of the greater lab curriculum. Our survey administered at the end of the A17 term, as shown in *Appendix D: A-Term Survey*, showed that just over 80% of students did not think that the labs prepared them well, or very well for the final exam. Additionally, just over 60% of students felt that the labs the labs did not prepare them for the final project well at all. The A17 survey clearly shows that students do not see the labs as a constructive section of the course when measured against the existing final project and the final exam. In the interviews we conducted, every Student Assistant stated that the labs suffered from a lack of cohesion and did not build up to the final project in a meaningful way. The complete Lab evaluation chart can be seen in *Appendix L: Lab Evaluation Table*

### [Lab Evaluation Chart Online](#)

#### Preliminary Design Review (PDR) & Cumulative Design Review (CDR)

One of the aspects of the course we desired to investigate for our IQP were the two Design reviews. During their progress toward the final project, students are required to complete a Preliminary Design Review (PDR) and Cumulative Design Review (CDR) in order to make sure they are on track with their final project. These design reviews are currently not graded. The reason we desired to investigate this aspect of the course was based on our preliminary research. According to C.M. University (2016):

If both product and process are important to you, both should be reflected in students' grades – although the weight you accord each will depend on your learning objectives for the course and for the assignment.

Currently the PDR and CDR are the only tools that have been implemented in the course to assess student progress on the final project, yet they have no impact on students' grades. Instead, almost the entire weight of the final project is based on the performance and completeness of the final project. If some weight was given to the PDR and CDR, it could help balance how much student evaluation leans toward product versus process. Grading the process can incentivize students to put more work into the project earlier in the term. This notion is supported by our student interviews. Teams that took the PDR and CDR process seriously often greatly benefited from it:

NG: What is your opinion of the design reviews, the PDR and the CDR?

Student #3: I really like their timing for that course. They make sure that you did everything out in advance. They're just really helpful.

NG: As a result of them did you change your design?

Student #3: Yes we did. In the PDR we realized that the mechanism we had all planned out and CADed, it just wasn't gonna work. I couldn't get certain positions, so we had to completely redo that. We might not have realized that until much later without it.

(Student Interview #3, February 26, 2018).

As we can see by this student interview, the PDR and CDR process can be quite effective when teams take it seriously. However, students don't always take the PDR and CDR process seriously. As stated in SA interview #4 and 1:

The advice given by especially the professors in accomplishing this final project is phenomenal, but again because the PDR/CDR aren't really graded students don't take them seriously. (SA #4, 1/18/2018)

Sometimes in the past it seems as though students were not prepared for it because they're not entirely sure what they're presenting because this is their more or less first time doing the CDR and the PDR. (SA #1, 1/18/2018)

Furthermore, as stated in the literature review, one of the stated goals of the RBE 2001 course is to develop team-working skills among students. Our research on creating effective team working skills showed it is important to assess not just the team's final product but also their process towards its completion. This encourages students to put in quality work earlier in the course, preventing teams from falling behind and having to attempt to rapidly finish in the final days of the term. A phenomenon that happens frequently in the course according to an SA Interview when asking if students finish the final

project on time: “By majority no, in my case as a student I was just barely able to finish both projects.”  
(SA #4, 1/18/2018)

In conclusion, if the PDR and CDR were graded they could potentially improve the course in several key ways. First, it would incentivize students to get working on the final project sooner and reflect more critically on their design in order to ensure they get a good grade on their PDR or CDR. Secondly it would provide an opportunity to grade students on the process rather than the product. Grading the process incentivizes better teamwork and gives students who are following the correct steps early on a bit of grade security.

## 4.2 - Created Materials

### Instructional Videos

One of the goals of this IQP was to create supplemental materials to aid students with common points of confusion. For this we made two videos, a new oscilloscope tutorial video to replace the old one made by a past IQP (Robotics Curriculum Enhancement - IQP 2016) as well as an introduction to object oriented programming video. The reason both of these videos were chosen was based on our research problems with the course indicated that these areas could benefit from additional content for the students to utilize.

The main reason we chose to do the oscilloscope video was that the original video lacked several key topics such as triggering the signal. In addition, the oscilloscope video made by this IQP was done on a much older model of oscilloscope than the one that is currently used in the lab. The oscilloscope is an excellent candidate for this supplemental video format because while many students struggle with it at first, there is also a sizeable portion of the class that have potentially worked with oscilloscopes extensively in the past as ECE double majors and thus will have no trouble using them. The video format allows those who do not have that earlier exposure to the material to familiarize themselves with oscilloscopes without spending the time of those that do possess that knowledge in lecture. The video was also broken down into sections so students could familiarize themselves with the parts that they felt they needed most. The topics covered by the video are testing probes, triggering your signal, scaling the waveform, measuring the waveform, analyzing a circuit, and capturing data. Additional supplemental oscilloscope learning resources were also linked in the description.

Oscilloscope Video: <https://www.youtube.com/watch?v=sG13N3v9kRE>

The second video we decided to make was an introduction to Object Oriented Programming oriented specifically at the students in the early RBE Unified Series that do not have as much exposure to computer science as some of their peers. The reason that this video was selected is that again like the Oscilloscope, many students in the course are already skilled in object oriented programming or



have almost no experience with it depending on if they are a Computer Science oriented RBE student or not. By making it a supplemental video resource, those students who need the most help with this material can seek it out outside of lecture. As stated by one of the SAs for the course when speaking on where students struggle with the final project:

Particularly people without a strong CS background who don't understand encapsulation and objects and such really struggled with the Bluetooth, even though it's not a particularly difficult thing to do, if you have that background, it makes a lot of sense, if you don't, it's a mess of words. (SA Interview #3, January 24, 2018)

The video was also broken down into sections so students could familiarize themselves with the parts that they felt they needed most. The topics covered by the video are a brief overview of functional programming, objects, classes, an example using the Servo library, and a walkthrough of making your own object. Additional supplemental object oriented learning resources were also linked in the description to cover important topics that were beyond the scope of the video.

Object Oriented Video: [https://youtu.be/mQAc4skF\\_rl](https://youtu.be/mQAc4skF_rl)

## Function Generator

The third piece of supplemental material we wanted to create was a way of better conveying how to use the function generators. Previously, Robotics Curriculum Enhancement - IQP 2016 created a video that provided a rudimentary overview of the device, but over the course of our IQP it became apparent that the function generator was still a point of confusion for students in RBE 2001 and other robotics courses. The decision to produce a document to cover this material instead of a video was made after a review of the manufacturer's user manual showed that a video would not be as conducive to understanding the material as well as a properly formatted document would be. Furthermore, use of some aspects of the function generator do not require understanding of other aspects, and therefore a short document that allows users to quickly glance at the information that is relevant to their specific use case would allow the user to obtain the relevant information without having to watch an entire video. The document we produced provides an overview of the entire user interface of the device and provides descriptions for each part of the device that a user would interact with. The function generator guide can be seen in *Appendix I: Function Generator*.

## Bluetooth

Just to get it to work requires almost no effort, so as far as an actuation mechanical challenge, it's not a hard one. The thing that people struggle the most with on the final project is the

Bluetooth. Far and away, they struggle the most with the Bluetooth (SA Interview #1, 1/18/2018).

Many of our interviews concluded that students struggle with the Bluetooth, and that programming takes a disproportionately large portion of time considering the main focus of the course, actuation. Unfortunately, the communication platform for next year is undecided, but in the meantime, minor improvements can be made to improve the Bluetooth section of the final project to help students who are newer at programming understand their objectives, and the actions required to obtain those objectives. Students who are preparing to approach the final project are provided with a large number of documents with an overwhelming amount of text to comb. It was difficult to find any direction on what must be completed to finish the final project while sorting through the various documents. The various documents were not titled or organized in a way that was easy to understand, which could cause a confused student to give up, or prioritize something easier to understand, which happens somewhat often, as referenced by multiple interviewees. For example:

It's not that it's particularly hard to do especially with the changes that have been made to the libraries the last couple years, they just don't start it early enough to work through the... "Hey we actually need to do this Bluetooth stuff" (SA Interview #1, 1/18/2018).

While students who are more advanced at computer science may be able to figure out the state of the program and compare towards the rubric, students with little programming experience would instead be lost and overwhelmed. The information provided in a very dense format, with many pages of information. This experience lines up with anecdotes of students pushing off the Bluetooth portion until the final day, which results in many students failing to complete the Bluetooth portion. To combat this issue, some minor changes to the organization of documents, the documents themselves, as well as to the GitHub repository were made in order to improve clarity for students inexperienced with programming or with difficulty understanding object oriented C++ programming. The most major of these changes was created in the README of the GitHub, which now contains instructions on how to start the final project and the order to read the documents provided, as well as giving them some direction on how to complete the project. We considered a major overhaul of the Bluetooth code, but due to the upcoming summer review and the new platform, which will use a different communication protocol, we decided that adding some direction in the meantime was an appropriate use of time. In the future, the upcoming Wi-Fi project documentation should be clear and easy for students to follow.

#### Class Hardware

Almost every interviewee stated that different parts of the class hardware are an issue. The VEX metal pieces students use for RBE 1001 and 2001 are worn and old, formed from weak steel, are easy

to bend by hand. The lab organization for hardware such as shaft collars, shafts, and VEX metal pieces is very poor, making it difficult to find a straight, flat, correct size part. Due to the limited quantity of important items such as shafts and shaft collars, by the end of the course the only remaining pieces are unusable due to their size or condition. The drawer for students to find screws contains hundreds if not thousands of screws in incorrect sizes, a problem that is only exacerbated by students removing screws of the correct size, leaving students with little choice but to purchase personal nuts and bolts to complete their project by the end of the course. Due to the limited supply and uncontrolled nature of lab resources, students often grab as many resources they can towards the beginning of the class and hoard items, to ensure they will have enough for themselves to complete their project, leaving many teams missing vital components of their robot while they remain unused in another team's bin, resulting in a "tragedy of the commons". In order to avoid using the provided lab materials such as the low-level flame sensor, or the VEX light sensors, many students purchase their own high-quality equipment of high-level sensor packages. With the move to Foise, new equipment should be purchased to reduce the time students spend on trying to get their equipment working. Unit testing equipment will also help cut time that students spend on debugging hardware.

### Final Project

As a result of our surveys, interviews, and conversations with the course staff; a need for an updated final project for the course was established. There were many contributing factors to this decision the largest ones being:

- Students know what designs work by looking to the past and build proven robot designs every year.
- The current final project is very Computer Science (CS) heavy and not very Mechanical Engineering (ME) heavy in terms of difficulty.
- The current theme for the final project of nuclear rod replacement is outdated as robots in the real-world robots are not used for this application and not likely to be used for it in the future. There exist alternative themes that are more in line with developing fields of robotics.

### *Project Overview*

Our recommendation for the new final project for RBE 2001 is contained in *Appendix J: New Final Project Description*. A brief overview of the project is as follows: each team of students is required to make at least one robot to complete the challenge, robots are required to retrieve objects from the Pick Up location, pass through a Gate that is fourteen (14) inches wide and ten (10) inches

tall, place the object retrieved from Pick Up into a Storage Slot in Long Term Storage, retrieve an object from Long Term Storage, pass back through the Gate, and finally place the object in the Drop Off location.

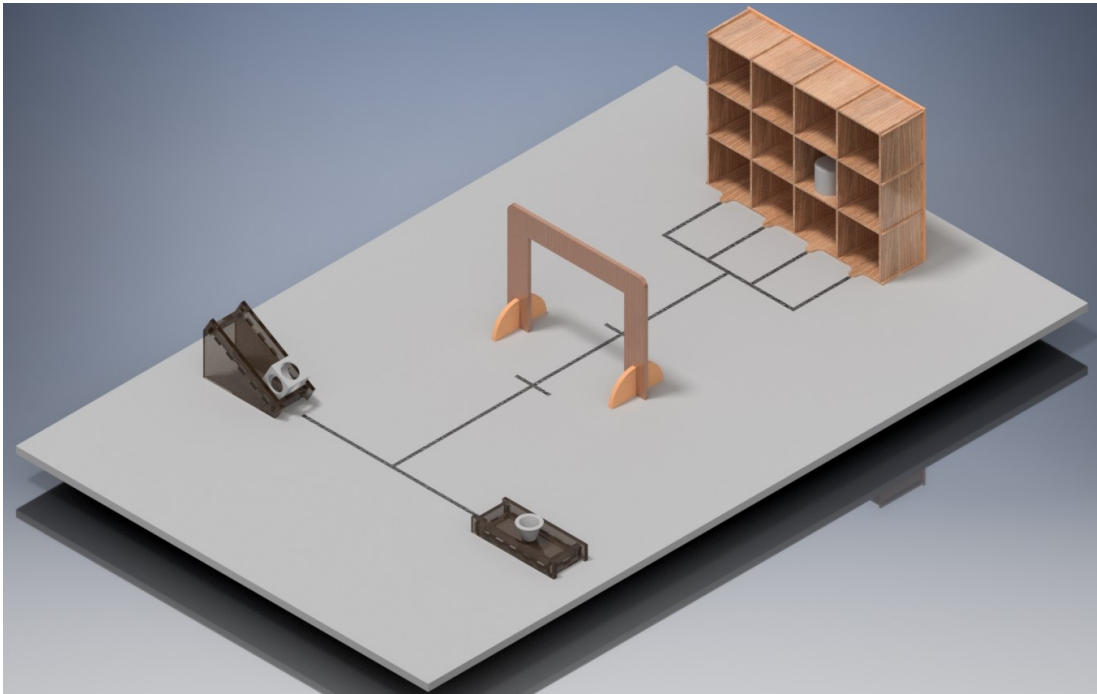


Figure 1 - Final Project Field Render

Field communications should be utilized to inform robots of the correct Storage Slots to use as well as which location they should travel to next, as the field itself will be dumb (contain no electronics and be entirely passive). Long Term Storage is a structure comprised of twelve (12) Storage Slots (four wide and three tall), each of which is a six (6) inch cube on the interior. The Pick Up location is a sloped acrylic trough that allows the objects to slide down to its base for easy access. The Drop Off location is a flat acrylic trough that allows for robots to place objects within it easily, as it is at the same angle as the Storage Slots in Long Term Storage. Line follower paths have been designed connecting each section of the field, as well as the inclusion of warning lines on either side of the Gate to allow robots enough time to transform themselves into a more stowed position.

### *Theme*

The theme that we selected for our recommendation was that of a 'Warehouse Robotics' type challenge, similar in style to the solutions that companies such as Amazon Robotics (formerly Kiva Systems), Symbotics, Ocado, and others use today. This recommendation was suggested to us by Kevin Harrington, the lead Lab Manager, and aims at updating the challenge to have a more modern feel analogous to some of the most successful robotics solutions in the market today.

## *Project Design*

When working on the design of the new field the difficulty of the challenge in terms of CS and ME was taken into serious consideration. The reasoning behind this being that currently students struggle a lot with the Bluetooth communication, keeping accurate track of the robot's state in the field (where it is and where it is going), and general understanding and execution of object oriented programming concepts. All of these topics, while very important, are not intended to be the main challenge of this course as *RBE 2001: Actuation* is intended to have a focus on ME concepts relating to actuation such as four bar design and analysis.

In terms of decreasing the CS complexity, the field design involves less complex intersections along the line following paths as well as fewer locations to travel between, thus making it easier to program the state machine that keeps track of what the robot is actively doing. Multiple fields have been designed with varying difficulty levels by adding multiple Pick Up and Drop Off locations to allow the potential for robots to be required to interact with specific Pick Up locations instead of others, this allows for extra credit opportunities to exist in that different Pick Up locations could contain objects of varying difficulty.

In terms of increasing the ME complexity, the two large ME aspects of the project are the end effector and the actuation method used to move the end effector with respect to the robot frame. For the first of these two ME aspects, the end effector, complexity was increased by including a variety of possible objects for use in the final project. The second of these ME aspects, the actuation method, was made to be more difficult by having multiple end positions required to access all the Storage Units instead of just two, as well as requiring the actuator to be able to have the two configurations of stowed (to fit below the height barrier) and extended (to reach the higher storage locations). To allow greater creative freedom, the requirement of a four-bar has been removed to allow students to utilize a wider range of actuation methods. Creative freedom was another focus of this final project redesign, as Professor Miller states:

I'd like to be able to keep it that way so that there's opportunities for students to come up with very creative solutions and kind of you know think outside of box... (Professor Miller, 2/8/2018)

The objects, which the robots are required to transport around the field, have been enlarged and their weight increased to add greater importance to the mechanical analysis that teams are required to perform prior to building their robots. The greater weight of objects was a request made by several interviewees both during their interviews and after:

You had to reach somewhere higher from a small starting configuration and lift something heavier, or something that would require more in-depth mechanical analysis and actual more

robust mechanical design I think would be more in line with the rest of this course. (SA Interview #2, January 19, 2018)

Increasing object weight requires students to put more thought and effort into the design of their actuation methods and end effectors because the loads they will be interacting with will no longer be negligible. Based on our research and calculations an appropriate maximum weight for these objects to be is approximately half a pound.

To prevent the potential pitfall of students choosing actuation methods that are unreliable, poorly designed, or unrealistic, we recommend that students must have their chosen actuation method approved by course staff during the PDR process. Additionally, robots will be required to pass through a size limiting structure between the two main zones they operate in to force robots to interact with field elements above their own maximum stowed height.

### *Field Variety*

The new final project field was designed to allow for varying levels of navigation difficulty via implementation of changes to the layout of the layout of the field. The initial design used two long flat troughs as the Pick Up and Drop Off locations, as seen in *Appendix K: Supplemental Final Project Images Figure 4*, but concerns were raised as to the difficulty of locating the objects in the troughs as well as the orientation of the guiding line leading to the troughs forcing teams to design robots that could interact with objects alongside the direction of travel. To accommodate these difficulty concerns about the flat troughs, and to make the project more realistic, the Pick Up location was changed from a flat trough to an inclined trough with designs made with both 45° and 30° inclines. The use of an inclined surface as the Pick Up location ensures that all objects within the Pick Up location will be against the wall on the lower end, but still includes the difficulty of localizing the object horizontally; additionally the objects tilt will now need to be accounted for when robots try to place objects in Long Term Storage to ensure that the objects do not fall out and are completely contained in their designated Storage Slot. Other fields range in difficulty, from a field that is much smaller with much simpler navigation (*Appendix K: Supplemental Final Project Images, Figure 5*), to a field that has multiple Pick Up and Drop Off locations allowing for more complex navigation requirements (*Appendix K: Supplemental Final Project Images, Figure 3*).

An alternative project design that was also considered was a more vertically focused challenge that would require robots to be very narrow, to reach objects three times their stowed height, as well as manipulate complex shapes. This option was decided against because it does not allow students as much freedom in their design process.

## *Platforms*

As part of the improvements being made to the course, a new architecture for the class is being chosen to replace Arduino. To replace the Arduino, the ESP8266 microcontroller was chosen. The ESP offers two major advantages over the Arduino, firstly, the speed of the board is significantly higher than the Arduino, at 16 MHz for the Arduino Mega 2560 used in the class compared to 80 MHz for the ESP8266 onboard processor (Arduino; SparkFun Electronics). A faster board will allow the I/O pins to read and write data at significantly higher rates, allowing them to serve interrupts on time and read high data rate signals such as encoders. Secondly, the ESP has a built-in Wi-Fi chip, allowing it to communicate over wireless internet protocols. This allows the library for the communication to be nicely packaged in a way that is easy for students to understand and work with, as compared to Bluetooth, due to the packet structure. Wireless internet will also be significantly more reliable than the Bluetooth chips being used currently, which often disconnect or are very difficult to connect to reliably. These improvements over Bluetooth will alleviate many of the courses key issues, such as those mentioned by Professor Bertozzi in his interview, along with the revisions to the final project. Some attention to detail must be placed on the Wi-Fi library documentation to ensure students may spend an appropriate amount of time becoming accustomed and being able to work in the library, or students might struggle with the potentially difficult programming required for a full implementation. It is possible to program ESP chips using Arduino, hopefully making the transition process significantly less painful, while also retaining backwards compatibility.

## *Scoring*

The existing materials detailing the scoring method of the current final project exist in two places: the final project descriptions' section about scoring and the final project demo rubric. Both scoring descriptions totaled to a different number of possible points and had subjective scoring guidelines for several scoring categories. To ensure that the new final project scoring criteria were easier to understand, easy to find, and were to be fair, we included the scoring rubric as an appendix of the final project outline and wrote brief descriptions of each score so that students would have a good idea of what each possible score represents. In regard to the numbers selected for the weights the focus was placed on the key aspects of the project and more weight was given to the mechanical aspects of the robot design instead of the programming aspects.

## 5 - Conclusions and Recommendations

In conclusion, the effectiveness of our IQP at increasing the learning efficiency of the RBE 2001 course has yet to be determined. This desired result will depend on both the quality of our work and how our recommendations are taken into consideration by the RBE Program at WPI. It can be said however that we were successful in our two primary goals that were designed to help us achieve our ultimate goal of increasing learning efficiency. These goals were recommending improvements to existing materials and the creation of new course materials. This section will summarize the recommendations and achievements of our work.

### 5.1 - Recommendations for improving existing materials

Our recommendations for the improvement of existing material take two main forms, recommendations for improving the labs and recommendations about the design review process (PDR/CDR). For the labs, we created a Lab Evaluation Chart evaluating the individual components of each of the labs as well as recommended additions for labs on their relevance to the old final project, relevance to the recommended new final project, importance to the educational objectives of the course, and time difficulty. These elements were combined into a composite score and briefly justified with explanations. It is our recommendation that in the future when the RBE Program's Curriculum Design Committee is reviewing the labs in the RBE 2001 course, that they take into account our table when deciding what components could be added to the lab and what components could be removed from the lab.

For the design review process, which takes the form of the Preliminary Design Review and Cumulative Design Review (PDR and CDR), our recommendation is simply to grade them. The reasoning behind this is that they are in theory very good tools for making sure students are on track but in the status quo students do not take these design reviews seriously because they are not graded and the students are already busy trying to complete the graded parts of the course such as the labs. Furthermore, grading the PDR and CDR will provide students with opportunities to earn credit on the final project earlier in the term. This way, if the students are having a very difficult time finishing the final project near the end of the term; they will have some grade security provided that they were taking the appropriate steps to make progress on the final project earlier in the term for completion of their CDR and PDR presentations. We also recommend that the professors pay special attention to the dynamics of the group during the CDR and PDR. It can be extremely difficult to measure how well a team is working together, but through careful observation during the design reviews, it may become apparent that there is a problem with the team dynamics. As mentioned before, it may also be advisable to incorporate a team creation and evaluation software such as Purdue's CATME. The CATME software



named for the *Comprehensive Assessment of Team Member Effectiveness* is a web-based utility for professors to create student groups and have them evaluate themselves and their team member's contributions to a project. If used correctly, it can be an effective tool to prevent bad teamwork practices. This could take the form of one member doing too much work or other members doing too little. Beyond the use of team evaluation software, a well organized and design review presentation where all members participate and demonstrate an understanding of what they are presenting would be indicative of a good team work/group dynamics and should receive a good grade.

## 5.2 - Created Materials

In order to achieve our goal of improving learning efficiency of the course, several types of additional content were created. The first of this content took the form of supplemental videos made to support knowledge determined to be points of confusion among the students. The two topics that were chosen for these videos were how to use the Oscilloscope and Object-oriented programming. These topics were chosen because prior student knowledge on them varies dramatically depending on if students are double majors in the related fields (ECE and CS respectively). By having this content optionally available as supplemental videos students who feel they need more exposure to these skills and concepts can seek them out independently of lecture time. This allows lectures to focus on the content more critical to the education objectives of the course.

An additional resource we created for students was a document outlining how to use the Function Generators present in the RBE lab. It was decided that a short document that allows users to quickly glance at the information that is relevant what they are doing in lab would be most useful to students. This was chosen over a video because having to watch the video would interrupt student progress on the lab and be problematic in a loud lab environment. The document we produced provides an overview of the entire user interface of the device and provides descriptions for each part of the device that a user would interact with. The function generator guide can be seen in *Appendix I: Function Generator* .

### Bluetooth

As the eventual switch to the ESP and the new ESP library, that Kevin Harrington mentioned that he would write in the coming summer and beyond, the Bluetooth library will become deprecated. Until that point, to clarify student confusion over direction on the final project, a comprehensive README on how to approach the final project and its wealth of documentation. With any coming updates, this should receive a corresponding update, until the point at which the library is deprecated.

At this point, the README should be given a deprecation warning and be removed from all course materials in the updated final project. The new library should be suitably documented and commented in a way that is clear to students on how to proceed forward in the final project. From personal experience and anecdotal evidence, a large portion of lab time is spent on determining the actions that are required to complete lab objectives, in part due to some vague wording and student assistant inexperience during the development of a new class. For this reason healthy lab and project documentation, specifically in the upcoming Wi-Fi final project library, is mandatory as the new class is developed, or students may become overwhelmed with work, resulting in an increase in student failure and stress. We are confident in the lab manager's ability to create a well-documented final project library, but particular attention must be paid to ensure that it is readable from the perspective of incoming students.

## Final Project

As a result of the surveys and interviews we conducted, it was determined that a new final project was crucial to the future of this course. Some of the issues that were expressed about the current final project were that the theme was out of date, the programming it required of students was too complex, and that the mechanical engineering portions were too easy. To address each of these concerns was well within the scope of this project. To do this, a new theme (warehouse robotics) was chosen, the lines provided as paths for robots to follow were simplified (reducing state machine complexity), and the mechanical complexity required by the robot's design was increased in several ways. To allow the project to be relevant and feasible for numerous years to come, multiple fields and objects for robots to interact with were designed so that the project can change to fit the difficulty fit for the students at the time.

## 5.3 - Class Hardware

Improving the lab-kit hardware for the course will reduce the time students must spend on fixing broken and bent steel pieces. For a robot to be able to complete the precise challenges required of robotics students, their robots must drive in straight lines, especially in autonomous situations, which make up most of the robotics final projects. To do this with the VEX steel pieces is very difficult as they are frequently warped and bend at any strong moment or impulse, resulting in unsteady robots with difficult to control movement. Another problem are the VEX motor encoders, which Lab Manager Kevin Harrington even cites in his interview as being so inaccurate as to be misleading to students about the

overall quality of encoders in general (Harrington, 1/23/2018). This fundamental misunderstanding of encoders as pragmatically useless due to the extremely high noise to signal ratio which is common in VEX encoders in the wider robotics world results in poorly equipped robotics engineers to confront the servo motor dominated robotics industry, where highly precise and accurate digital encoders are commonplace. Examples are the encoders on Tesla Motors electric cars, or the precision encoders on modern robotics arms or even bipedal and quadrupedal robots. Upgrading the equipment to the school's showcase program is vital as part of the Foise innovation move, and will result in better engineers and also better public relations, which is key to sustaining the success of the robotics program at large. Higher quality sensors and higher quality hardware materials combined with improved lab materials will accelerate student learning and raise the bar for our graduating robotics engineers. Reducing the time students spend on figuring out hardware solutions using difficult hardware is important in their objective of reducing student learning time, as noted by Professor Bradley Miller in his staff interview (Miller, 2/8/2018). This can be achieved with higher level sensor packages and modern high-strength low-elasticity metal frameworks, which are common to robotics in the outer industry.

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## Appendix

### Appendix A: Program Objectives

**WPI COURSE CATALOG (2017-18):** [\(page 121 of pdf, 117 of document\)](#)

The WPI Undergraduate Catalog lists the following as the mission statement, Educational Objectives, and Program Outcomes of the Robotics Program at WPI:

#### **MISSION STATEMENT**

Robotics—the combination of sensing, computation and actuation in the real world—is on the verge of rapid growth, driven by both supply and demand. The supply side is driven by decreasing cost and increasing availability of sensors, computing devices, and actuators. The demand side is driven by national needs for defense and security, elder care, automation of household tasks, customized manufacturing, and interactive entertainment. Engineers working in the robotics industry are mostly trained in one of Computer Engineering, Computer Science, Electrical Engineering, Mechanical Engineering, and Software Engineering. No single discipline provides the breadth demanded by robotics in the future.

#### **PROGRAM EDUCATIONAL OBJECTIVES**

Graduates of the Robotics Engineering program are expected to:

1. Successfully
  - a. attain professional careers in robotics and related industries, academia, and government;
  - b. expand human knowledge through research and development; and/or develop entrepreneurial engineering activities.
2. Engage in life-long and continuous learning, including advanced degrees.
3. Exert technical leadership over multi-disciplinary projects and teams.
4. Contribute as responsible professionals through community service, mentoring, instructing, and guiding their professions in ethical directions.
5. Communicate effectively to professional and business colleagues, and the public.

#### **PROGRAM 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.

## Appendix B: Course Description

### **Course Objectives (from syllabus)**

Upon completion of this course, students will be able to:

1. Describe basic terminology related to the field of robotics.
2. Synthesize planar mechanisms to complete a specific task.
3. Formulate the position, velocity, and acceleration kinematics of a mobile robot in 2D.
4. Determine power system requirements and structural requirements using force analysis.
5. Specify DC motor requirements that meet a specified locomotion or manipulation task.
6. Write moderately involved programs in Arduino C/C++ to perform a specified task with a robotic system in real-time.
7. Specify appropriate electrical system design to convert battery energy into a controllable power drive signal to a specified DC motor.
8. Construct, program, and test the operation of a mobile robotic system to perform a specified task.

### **Description (from syllabus)**

First of a four-course sequence introducing foundational theory and practice of robotic engineering from the fields of computer science, electrical engineering and mechanical engineering. The focus of this course is the effective conversion of electrical power to mechanical power, and power transmission for purposes of locomotion, and of payload manipulation and delivery. Concepts of energy, power and

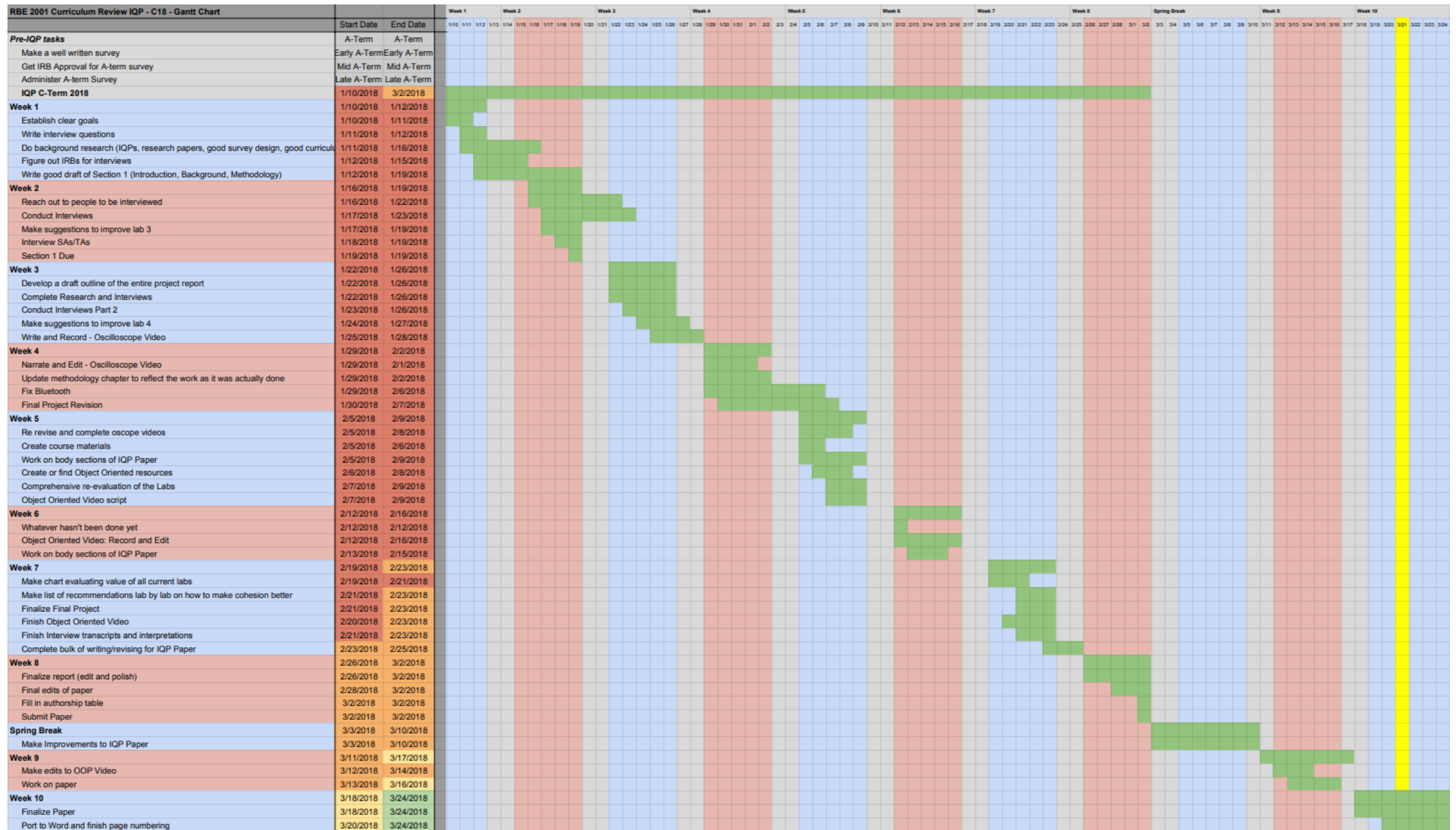
kinematics will be applied. Concepts from statics such as force, moments and friction will be applied to determine power system requirements and structural requirements. Simple dynamics relating to inertia and the equations of motion of rigid bodies will be considered. Power control and modulation methods will be introduced through software control of existing embedded processors and power electronics. The necessary programming concepts and interaction with simulators and Integrated Development Environments will be introduced.

**RBE 2001. UNIFIED ROBOTICS I: ACTUATION. *Cat. I***

First of a four-course sequence introducing foundational theory and practice of robotics engineering from the fields of computer science, electrical engineering and mechanical engineering. The focus of this course is the effective conversion of electrical power to mechanical power, and power transmission for purposes of locomotion, and of payload manipulation and delivery. Concepts of energy, power and kinematics will be applied. Concepts from statics such as force, moments and friction will be applied to determine power system requirements and structural requirements. Simple dynamics relating to inertia and the equations of motion of rigid bodies will be considered. Power control and modulation methods will be introduced through software control of existing embedded processors and power electronics. The necessary programming concepts and interaction with simulators and Integrated Development Environments will be introduced. Laboratory sessions consist of hands-on exercises and team projects where students design and build robots and related sub-systems.

Recommended background: ES 2201/RBE 1001, ES 2501 (can be taken concurrently), ECE 2029 and PH 1120 or PH 1121

Appendix C: Gantt Chart





## Appendix D: A-Term Survey

### Questions

Intro:

This short (less than 5 min) survey is designed to provide constructive feedback on the RBE 2001 curriculum.

Multiple choice:

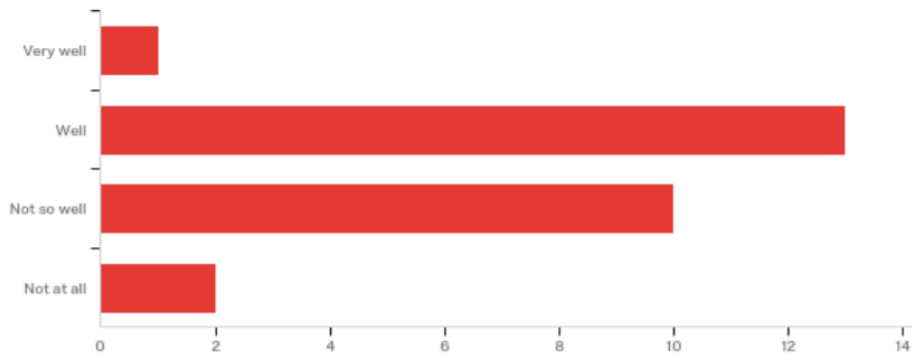
1. To what extent did the lecture material prepare you for the final project?
  - a. Very well
  - b. Well
  - c. Not so well
  - d. Not at all
2. To what extent did the lecture material prepare you for the final exam?
  - a. Very well
  - b. Well
  - c. Not so well
  - d. Not at all
3. To what extent did the labs prepare you for the final project?
  - e. Very well
  - f. Well
  - g. Not so well
  - h. Not at all
4. To what extent did the labs prepare you for the final exam?
  - i. Very well
  - j. Well
  - k. Not so well
  - l. Not at all
5. There is too much overlap with RBE 2001 material and material covered in other WPI classes.
  - m. Strongly Agree
  - n. Agree
  - o. Neither agree nor disagree
  - p. Disagree
  - q. Strongly Disagree

Short Answer:

1. What topics do you think should not have been included in this course, and why?
2. Were there topics that would have helped you complete the course that were not included? If so list examples.
3. Would your current knowledge of the robotics program at WPI affect your decision to attend WPI or to be a robotics engineering major? Please explain why.
4. Are there any other comments or concerns you would like to tell us about the RBE 2001 course?

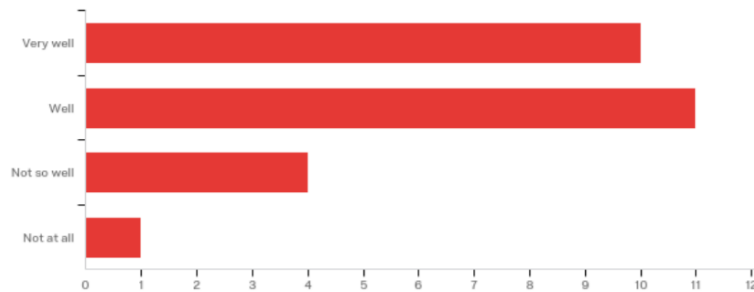
### *Multiple Choice*

**Multiple Choice - Question 1: To what extent did the lecture material prepare you for the final project?**



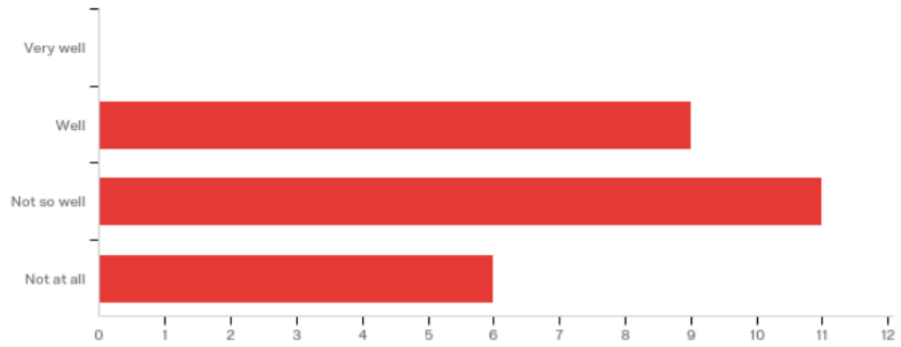
#	Answer	%	Count
1	Very well	3.85%	1
2	Well	50.00%	13
3	Not so well	38.46%	10
4	Not at all	7.69%	2
	Total	100%	26

**Multiple Choice - Question 2: To what extent did the lecture material prepare you for the final exam?**



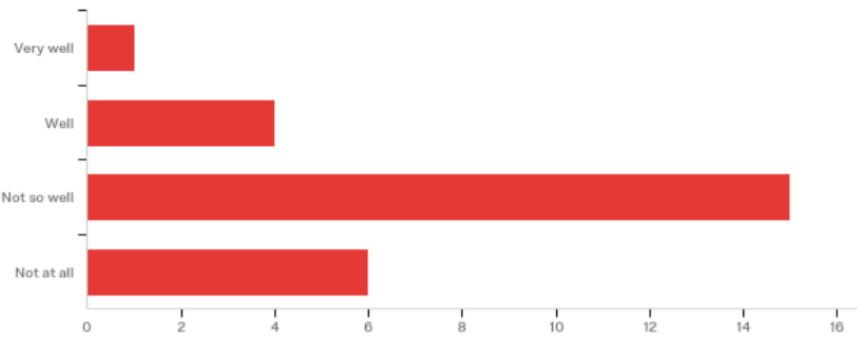
#	Answer	%	Count
1	Very well	38.46%	10
2	Well	42.31%	11
3	Not so well	15.38%	4
4	Not at all	3.85%	1
	Total	100%	26

**Multiple Choice - Question 3: To what extent did the labs prepare you for the final project?**



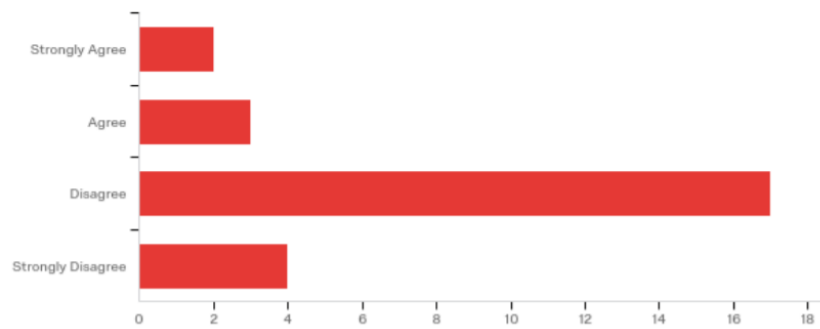
#	Answer	%	Count
1	Very well	0.00%	0
2	Well	34.62%	9
3	Not so well	42.31%	11
4	Not at all	23.08%	6
	Total	100%	26

**Multiple Choice - Question 4: To what extent did the labs prepare you for the final exam?**



#	Answer	%	Count
1	Very well	3.85%	1
2	Well	15.38%	4
3	Not so well	57.69%	15
4	Not at all	23.08%	6
	Total	100%	26

**Multiple Choice - Question 5: There is too much overlap with RBE 2001 material and material covered in other WPI classes.**



#	Answer	%	Count
1	Strongly Agree	7.69%	2
2	Agree	11.54%	3
3	Disagree	65.38%	17
4	Strongly Disagree	15.38%	4
	Total	100%	26

### Written Response

#### Short Answer Question 1 - What topics do you think should not have been included in this course, and why?

how to grow potatoes

Shear and tension analysis

Mathcad should be done away with and replaced with software such as Matlab that is actually used later on. There should also have been a greater focus on real examples and practice doing the work instead of wasting class time trying to be relevant with videos of Bon Jovi.

materials, we had no homework or labs involving it and it was one lecture in which we could have done more project relevant material.

There's this last bit on materials science and strain calculations that just came out of nowhere. I understand that it's important to overall robots and such, but, like, it should be incorporated better if included, or just eliminated from the curriculum (my recommendation is the latter, as it would provide an additional class period or two to process the already overwhelming amount of information provided by this class)

Algadoo and Norton linkage software. We all ended up using solidworks to solve our linkage problems, it is more than good enough.

I haven't taken many courses other than humanities and math at this point, so the subjects covered here were useful to me, I have no objections ...

Algadoo seemed unnecessary since we were also taught the Linkage software.

Algadoo was useless.

position and velocity analysis, op-amps

Thevenin & Norton is nice, but it's little more than an advanced trick for analyzing circuits. It's in no way critical to the final project, nor to a large number of practical applications. Considering its limited use, I don't think we should have spent so much time on it.

No but I feel that more focus on some of the parts that more people struggled on would have greatly helped.

There should have been more overlap with the lecture and final project. Same goes for the labs. There was minimal overlap between them and that killed me for the final project.

Power requirements in a robotics system and steering systems seemed to be somewhat out of place. They're useful information for later, but seemed to not fit into class as we weren't tested on it or really needed to apply much to the final. I guess it's okay as a useful tidbit for the future but it may be better to spread out some other lectures into those days.

PID control was over emphasized in the course and did not pertain to our final project because we never got to implement it. This was also because we never got to that point because of other things and problems.

Bluetooth, the way it was implemented was too buggy with the app and seemed like an afterthought.

I am not sure specifically what parts of this course should or should not have been included, but I wish the course was more balanced between the three major parts of robotics. Both 1001 and 2001 are very mechanical-heavy.

**Short Answer Question 2 - Were there topics that would have helped you complete the course that were not included? If so list examples.**

how fukashima happened

We did not do as much computer science as I felt was necessary to complete the final project. Many assumptions were made as to how much we actually knew so as someone who had zero outside computer science experience, they either need to reevaluate their expectations or get better at actually teaching the material they expect us to know.

I think more on programming, we may be taught concepts but not many people have the language background for coding and don't know it well

Basically, I have a difficult time doing anything if I don't see how it is relevant; if I don't care. Much of the time in-class I spent doing the homework, as that directly related to the final project, and doing homework for other classes, again, as that was more relevant to my life and what I was doing. If lectures related more directly to the robot, and specifically addressed the final project, I would be more apt to pay attention, and therefore be able to understand the material better. If TAs and SAs and professors didn't scoff at things students have asked in the past, people would be more apt to ask questions, and

therefore would be able to understand the material better.

There were several major issues on our final robot because my group didn't have a ton of experience building a robot. It would have been nice to have one lecture of tips and tricks for building. For example, how to avoid skipping gears.

More programming for others

Programming libraries and coding long programs effectively.

Yes, more lessons on programming would have been helpful for the final project.

While interrupts were discussed theoretically, how to actually code them was not. Bluetooth was somewhat covered but how to actually code with bitmasks (which is essential for reading the messages) was barely and insufficiently covered.

more coding, more bluetooth, literally center the class on the final project but even more so. make the labs steps to creating the robot

We covered 3D design satisfactorily, but parts production (laser cutting, 3D printing) is not discussed at all in 1001 or 2001. We're just expected to figure it out for ourselves. It would be useful to learn how to deal with the offsets, tolerances, and parameters associated with different manufacturing techniques.

No

General Robot design and process

More in depth programming examples

Specific lectures/sessions for sensors recommended by professor (Pololu light array)

How to put programming concepts together to create a complete set of code for a robot.

Object Oriented Programming

More CS

More programming would have helped everyone in the final project. After doing mostly mechanical and electrical work in lecture and lab the final project was very different. Having a lab like the 1001 owl lab where you have to do something that's related to the final project on a smaller scale could help everyone grasp the programming concepts I saw people struggling with during the final, like state machines and line following. Maybe a lecture on line following would benefit people by touching subjects like the pololu line follower array and where to put it in relation to your VTC could help people with the final.

More of the CS aspect of the course. Also we should have done labs that prepared us for the final project. This being topics like classes, cpp, h files, how to keep your code clean and understandable.

It would have been helpful to spend more than one class learning about stress and material properties. Also, more in class example problems of all topics would have been helpful

More programming, examples of how to use state machines to control something like a robot arm sequence of actions. Ex: close gripper, lower arm, open gripper, etc.

General robot design as well as troubleshooting and diagnosing problems with your robot should have been explicitly taught; these are essential skills to have as a robotics engineer that we are expected to already know or figure out. I would also love it if more sample code was provided for state machines, and would appreciate more information on how to do simple pieces of labs or homeworks that it is assumed we know how to do or have access to (eg. How to run a code in Python, how to export a .csv file, how to edit a part in solidworks so that you do not have to re-mate everything, how to determine the resistor values on op-amps, how to read a schematic and use a breadboard, etc.)

While for any one of these skills, half of the class may already know how to do it, it should not be assumed that any of us do unless it was explicitly taught in a prerequisite class. Those of us who have taken all the prerequisites should not still feel as if we are behind or in the dark.

**Short Answer Question 3 - Would your current knowledge of the robotics program at WPI affect your decision to attend WPI or to be a robotics engineering major? Please explain why.**

i love everything

Yes, because there was so much more of a community in the lab than a walk by on a tour would have shown and I truly believe that once everyone sees how great the lab community can be, they would understand why we all stick with such a difficult major.

no, I love the topics and material but work load is excessive

Yes. It absolutely would. I liked robotics before coming here, but if I honestly knew the amount of bullshit that we are subjected to, and the professors/TAs/SAs just laugh off and say "yeah, that's just the way it is", when I can see clearly that that which we are complaining has a very easy solution. ALL TA/SAs need to be more thoroughly checked--there have been several SAs this term that have been less than helpful, (ie, telling us we should already know how to do something in a review session, and then not going over it, or complaining that they have to do work), and then I've gone to a SA from 1001 whom I know is extremely helpful to help my group with our 2001 stuff. Someone needs some semblance of people skills and a work ethic, along with a sense of compassion and general not-being-a-scary-asshole-ness in order to be a successful and helpful SA.

I would still go here, I love the hands on final project approach to the class

It is definitely really challenging and you have to juggle a project along with learning in this class and other classes as well as studying for quizzes and such, so it can be overwhelming, but at the end of the day, I really enjoy it because while often I want to throw my robot against a wall, it's still amazing to see

my ideas come to life. If anything, it has made me want to pursue this more, and try harder to understand the topics required for this major. I'm glad I went to WPI because the hands on part of the course is vastly different from the lecture portion, as you have to learn how to apply it.

No, although it is very time-consuming and challenging, I learned a lot through this course. It really allowed me to be hands on with what I am learning through project work.

I would be more hesitant about becoming a robotics engineering major, because the continuity between labs, lectures, exams, and the final project is a little bit underwhelming, and all expect skills coming into the course not covered by prerequisites or class material.

Yes, I am regretting my minor.

Nothing could ever stop me choosing to be an RBE major at WPI. That being said, I absolutely despise the end of RBE terms, because we never have enough time to finish our projects because we're kept busy with labs and homework until the final week. If labs ended one week sooner, all-nighters would not have to happen in the final week. Please, please, please give us more time to do our projects. We cannot do 15-hour labs each week (which almost never contribute to the knowledge we'll use on the final project) AND work on our final project as much as we need to. The RBE course system is badly broken and needs to be fixed.

No because conceptually the program sounds fine but the issue comes when actually n the course and things seem to go a lot faster and the work load heavier than initially expected.

It would not because robotics is a passion of mine that I want to persue. I would be hesitant to take 2001 because of how difficult it was. It was unnecessarily hard. It could be split into two classes easily.

I expected the labs parts to be in better condition. The VEX metal is so old and bad that it makes building out of it unnecessarily hard. Also, get rid of all the stupid screw sizes that nobody has used in that drawer ever and replace them with more 8-32 which people actually use, with literally any form of organization more than is there now. The expectations of what parts you're allowed to use from the lab need to be more clear, and really should be a decent amount of things given the cost of WPI (yeah yeah it's complicated). This was probably worse this term with the transition of the lab and miscommunication. This being said, it wouldn't really change my decision if I knew this.

No

No.

no



Absolutely; as much as I love robotics, I find the workload and the expectations put on students to be unreasonable and unhealthy, and I frequently contemplate switching majors, or wish I had attended a different school. As mentioned previously, I find that even if you have taken all the prerequisites, you are often not equipped to handle what RBE expects of you. I also have poured hours and hours of time into labs where, if a single sentence more of information had been provided, I would have finished in minute. In order to take RBE, I had to drop all of my hobbies and extracurricular activities and stop spending time with my significant other and friends, just to keep up with the workload, and as finals approached, even that was not enough. I would encourage anyone who enjoys robotics not to major in RBE at wpi.

**Short Answer Question 4 - Are there any other comments or concerns you would like to tell us about the RBE 2001 course?**

none at all

Labs should have built up towards the final project, they did not.

Homeworks were like extra labs, they were too long.

Professor did not show examples for some topics which appeared on the exam and only showed the theory and derivations.

There needs to be more lab equipment and more lab space for students, as well as more materials that are working and available to students for classes since everything seems to be broken or on its way to breaking

the work load is too much, I get we are supposed to be challenged but a final project, final presentation, final report, 7 quizzes AND two days of final exams is unnecessary. we still have 2 maybe three other classes that give us work loads and it's overwhelming when you find rbe 2001 takes up all your time

Have the labs actually associate with the final project.

Present course material in an easier-to-process fashion

HAVE MORE PREREQUISITES

-This goes for all robotics classes. Statics and Kinematics should be required for the FBDs, ECE 2010 for the circuits, at least CS 2102 for coding (CS 2303 would be preferable), if you're going to have stress analysis included in the class, ES 2001, ES 1310 would be a great help for the solidworks, and probably more but it's currently 7:30 am and I'm taking a break from my 2001 final project b/c I had not enough time to finish it earlier, so I can think of no more.

The labs are disconnected from the final lab. The h-bridge stuff is completely pointless, because most motor controllers dont use them anymore, and we generally wont need to build a motor controller.

The TAs and SAs are angels, and I just want to say thank you to all of them for being so available and trying so hard to help everyone. Also the professors are awesome and love to help clarify questions, so great job everyone!! (This probably wasn't what this section was for, but you guys should be thanked

anyhow)

The labs are extremely long for material that is not used in preparation for the final project.

It would be helpful if the labs were at least mostly applicable/built up to the final project, instead of being barely applicable. Furthermore, the bluetooth can sometimes be a bottleneck, as it is a large part of the final project, but has proportionally little emphasis everywhere else, and requires an android to test thus essentially saying "tough luck" to anyone who does not have one. Not all the kits had all the parts, and it's important to understand that having to push back one due date means more time is needed, and will often mean all following due dates may have to be pushed back as the extra time needed for the first assignment takes from the time needed for the next one and so on. due to the lack of continuity in material covered in labs, lectures, exams, and the project, this class took far more time out of the week than any other class, one could argue it took more than twice the time of a normal WPI class out of every week - do with that info what you will.

The labs should be steps in building the robot.

See above. Also, have a nice break!! :)

If course material from previous years are used, please make sure it's up to date so that it doesn't confuse labs.

When the SAs tell me to "google" the answers, they need to be re-educated on how to help students. There is a reason my lab grades suffered.

The exams are too long and contain too much material that was not focused on much in class.

There should be more happiness and fewer labs to make room for a joyful final project.

The TA/SA's are great. The professors are very helpful as well

It's a LOT of information and work. Lectures go by fast but the HW and Quizes are manageable. The help sessions put on by the SAs are awesome and helped everyone like crazy! My biggest suggestion would be to better integrate the final project with the labs such that either the labs are lighter to give more time for the final, or integrate things that are directly applicable to the final project into all the labs. The challenge could also be changed up to involve more complex mechanical systems to lift something more than a tiny rod, it just depends on what the goal of the project is.

They are great courses! Just the equipment and space should be upgraded

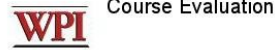
I felt the labs were very disconnected and did not have any direct connection with the final project or even the rest of the lab itself. One labs had one part of tracing paths of four bars and the second part of writing a PID controller. These had no relevance to each other and made it seem like we were completing 2 or 3 labs simultaneously. In 1001, the labs all built off of the lecture work and the previous work in the labs, leading up to the final project.

We need more lab space, it gets too crowded and loud.

I am very passionate about robotics, and I love what I do, but I have a very hard time with the RBE program and it makes it hard for me to continue liking robotics. It is physically and emotionally unhealthy for most people I have seen or talked to, and it has been very bad for the balance of my life. I also wish I had an easier way to voice my concerns about the program and learn about what steps are being taken (or what steps I can take) to improve it. That said, I am very grateful for this form.

## Appendix E: A-Term End of Course Evaluations

C01 - 17



Prof. Nicholas Bertozzi (as private and confidential)

RBE 2001 - C01 UNIFIED ROBOTICS I: ACTUATION for 201702\_C

Dear Prof. Bertozzi,

As part of WPI's student course report process, the quantitative results for each course section are distributed by email. These results will also be accessible on the Web Information System (Banner) under Faculty Services. The completed questionnaires are being returned to you via department mail. Students' written comments can be found on those forms.

This email contains the results for RBE 2001 - C01 UNIFIED ROBOTICS I: ACTUATION.

The responses to each question are shown in a histogram, with the number and average values of responses shown to the right. Please note that the number of responses listed in the header section of the report reflects the number of evaluations scanned. Since some blank sheets may be scanned, that number may be larger than the number of respondents.

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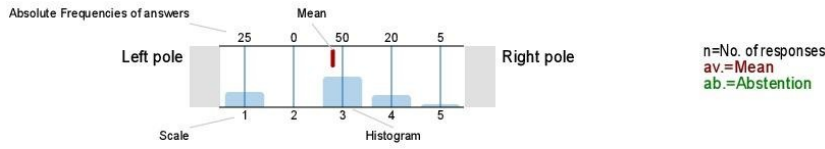
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Prof. Nicholas Bertozzi  
RBE 2001 - C01 UNIFIED ROBOTICS I: ACTUATION (201702\_C)  
No. of responses = 20

Survey Results

**Legend**

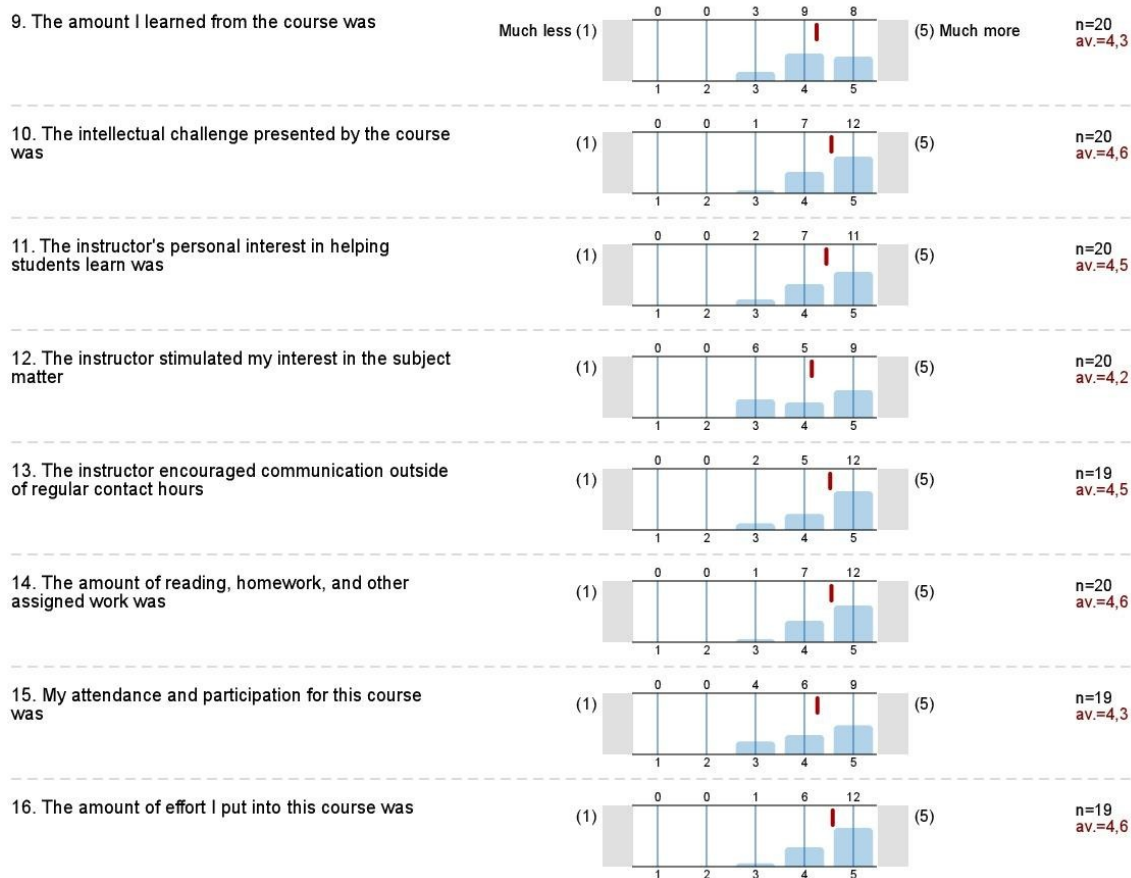
Question text



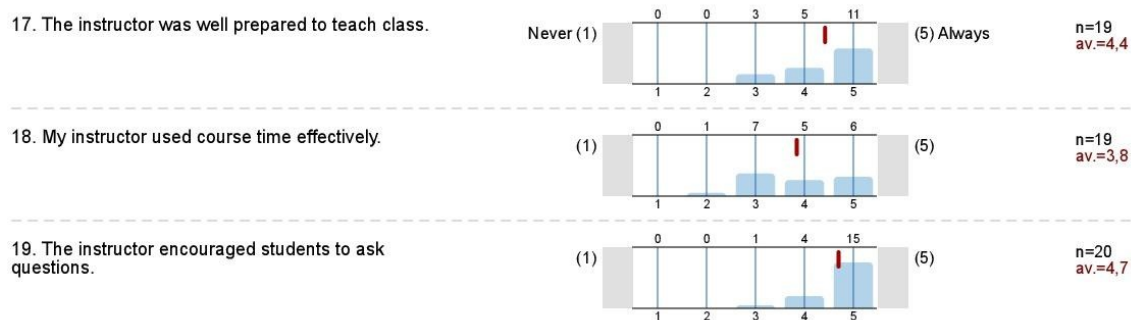
You can help improve the quality of teaching at WPI by providing your responses on this form. Please consider each reply thoughtfully. These reports are used by the instructor for self-improvement, by students during course selection and by members of the administration and faculty committees. Your responses are anonymous and optional. Your comments will not be returned to your instructor until after the grading deadline.

1. My overall rating of the quality of this course is		n=20 av.=4,1
2. My overall rating of the instructor's teaching is		n=20 av.=4
3. The educational value of the textbook and/or assigned reading was		n=17 av.=3,6
4. The educational value of the assigned work was		n=19 av.=4,3
5. The instructor's organization of the course was		n=20 av.=3,8
6. The instructor's clarity in communicating course objectives was		n=20 av.=4
7. The instructor's skill in providing understandable explanations was		n=19 av.=4,4
8. The instructor's skill in speaking clearly and audibly was		n=19 av.=4,7

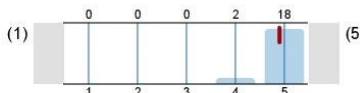
Relative to other college courses I have taken:



How frequently were the following statements true in this course?

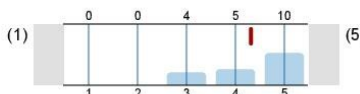


20. The instructor treated students with respect.



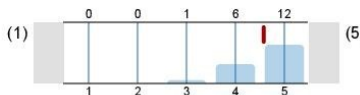
n=20  
av.=4,9

21. Instructor feedback on exams/assignments was timely and helpful.



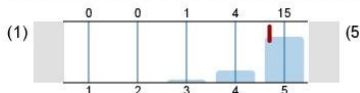
n=19  
av.=4,3

22. The exams and/or evaluations were good measures of the material covered.



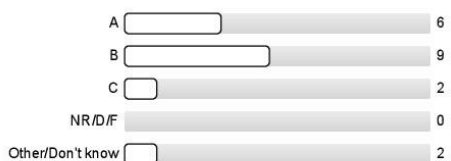
n=19  
av.=4,6

23. My grades were determined in a fair and impartial manner.



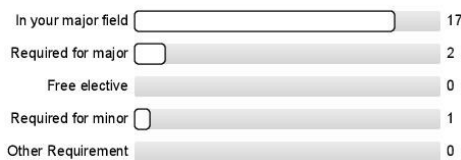
n=20  
av.=4,7

24. What grade do you think you will receive in this course?



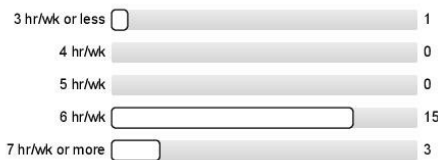
n=19

25. Which of the following best describes the role of this course in your academic program?



n=20

26A. On average, how many hours of the formally scheduled hours for lecture, conference, and labs did you ATTEND each week?



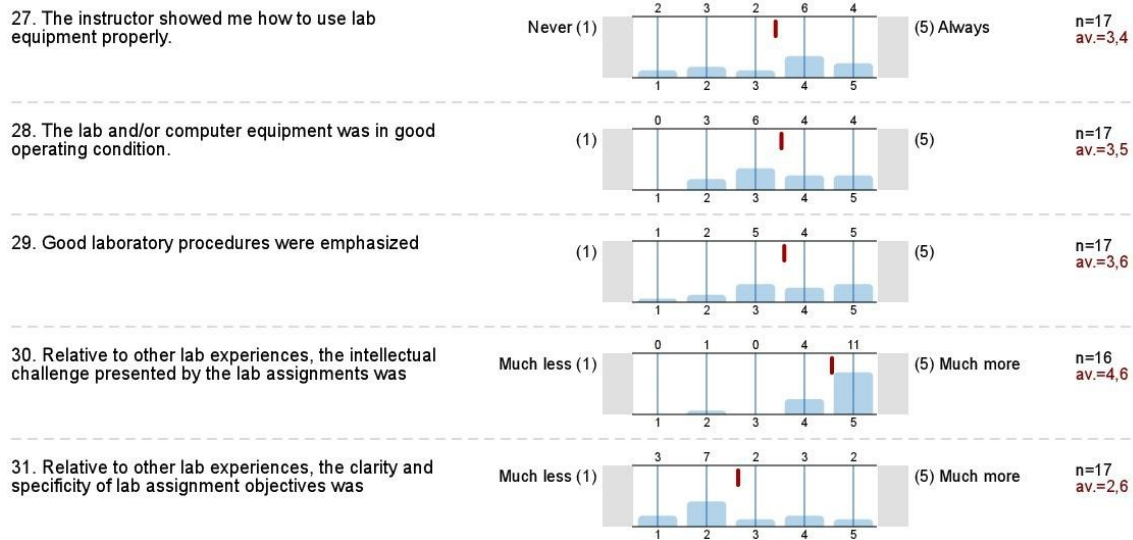
n=19

26B. On average, what were the total hours spent in each 7-day week OUTSIDE of formally scheduled class time in work related to this course (including studying, reading, writing, homework, rehearsal, etc.)?



n=18  
av.=4,7

For courses with laboratories only:



Please use the following to answer additional question(s) that may be provided by your instructor:

Instructor provided ranked question #1	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #2	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #3	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #4	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #5	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #6	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #7	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #8	The evaluation will not be displayed due to low response rate.



Prof. Nicholas Bertozzi (as private and confidential)

RBE 2001 - C02 UNIFIED ROBOTICS I: ACTUATION for 201702\_C

Dear Prof. Bertozzi,

As part of WPI's student course report process, the quantitative results for each course section are distributed by email. These results will also be accessible on the Web Information System (Banner) under Faculty Services. The completed questionnaires are being returned to you via department mail. Students' written comments can be found on those forms.

This email contains the results for RBE 2001 - C02 UNIFIED ROBOTICS I: ACTUATION.

The responses to each question are shown in a histogram, with the number and average values of responses shown to the right. Please note that the number of responses listed in the header section of the report reflects the number of evaluations scanned. Since some blank sheets may be scanned, that number may be larger than the number of respondents.

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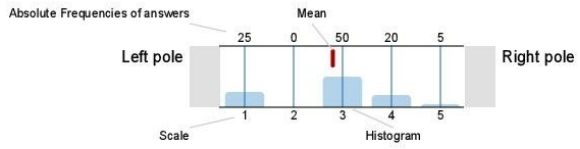
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Prof. Nicholas Bertozzi  
RBE 2001 - C02 UNIFIED ROBOTICS I: ACTUATION (201702\_C)  
No. of responses = 23

Survey Results

Legend

Question text

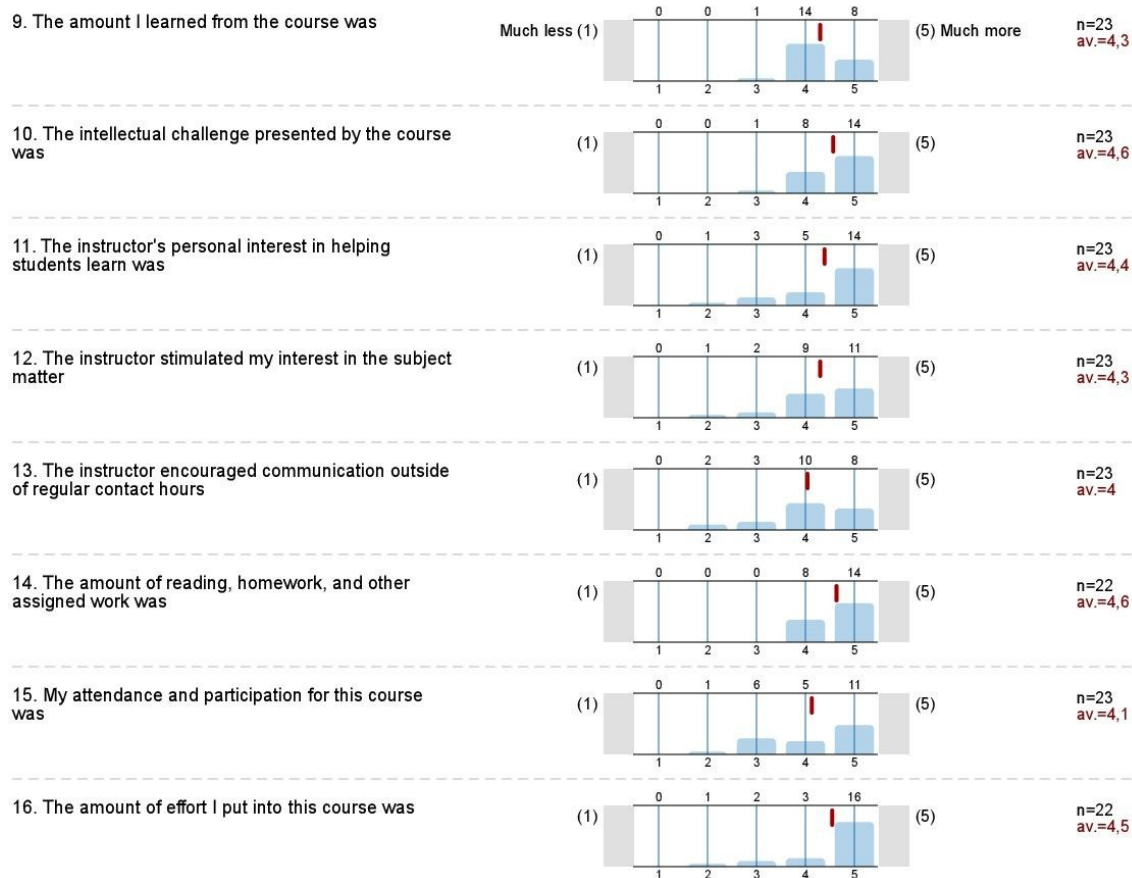


n=No. of responses  
av.=Mean  
ab.=Abstention

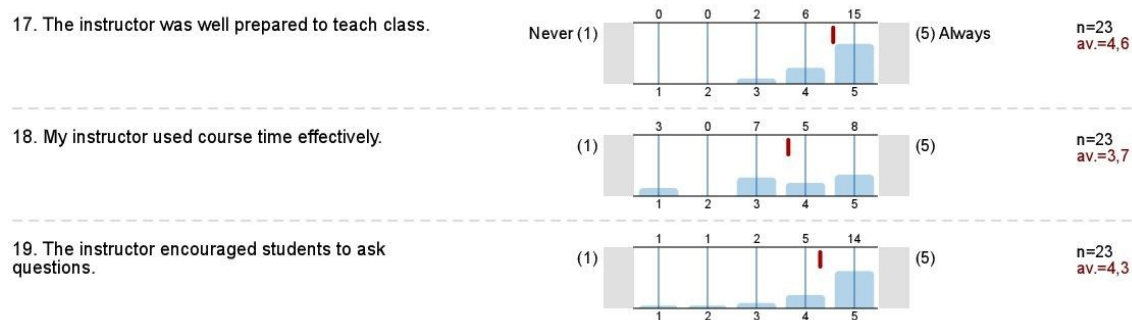
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1. My overall rating of the quality of this course is		(5) Excellent	n=23 av.=4
2. My overall rating of the instructor's teaching is		(5)	n=23 av.=4
3. The educational value of the textbook and/or assigned reading was		(5)	n=20 av.=3,2
4. The educational value of the assigned work was		(5)	n=22 av.=4,3
5. The instructor's organization of the course was		(5)	n=23 av.=3,7
6. The instructor's clarity in communicating course objectives was		(5)	n=23 av.=3,6
7. The instructor's skill in providing understandable explanations was		(5)	n=23 av.=3,7
8. The instructor's skill in speaking clearly and audibly was		(5)	n=23 av.=4,2

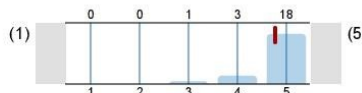
Relative to other college courses I have taken:



How frequently were the following statements true in this course?

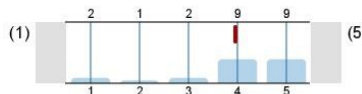


20. The instructor treated students with respect.



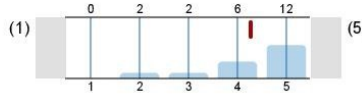
n=22  
av.=4,8

21. Instructor feedback on exams/assignments was timely and helpful.



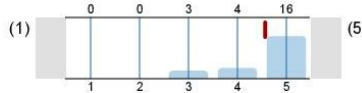
n=23  
av.=4

22. The exams and/or evaluations were good measures of the material covered.



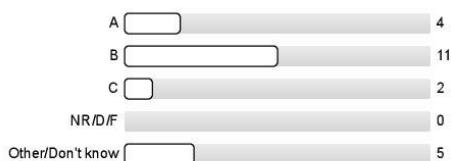
n=22  
av.=4,3

23. My grades were determined in a fair and impartial manner.



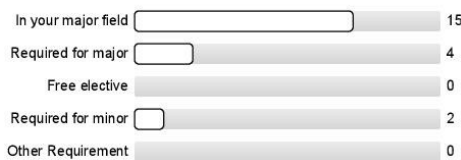
n=23  
av.=4,6

24. What grade do you think you will receive in this course?



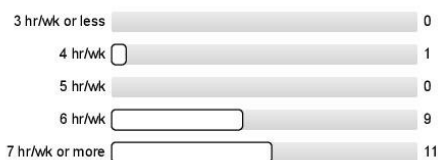
n=22

25. Which of the following best describes the role of this course in your academic program?



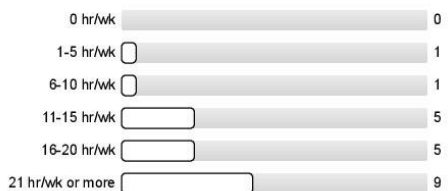
n=21

26A. On average, how many hours of the formally scheduled hours for lecture, conference, and labs did you ATTEND each week?



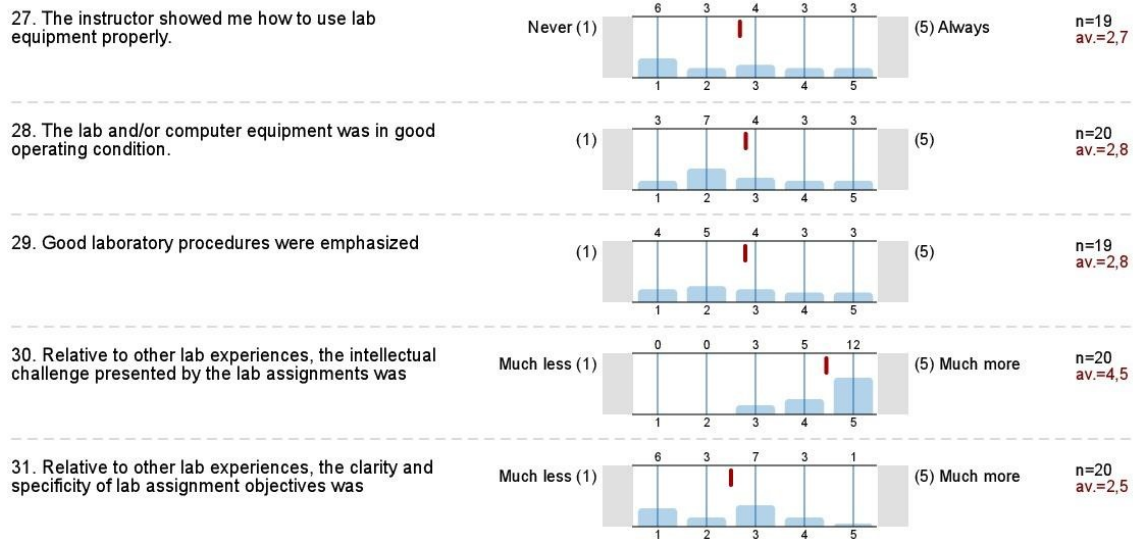
n=21

26B. On average, what were the total hours spent in each 7-day week OUTSIDE of formally scheduled class time in work related to this course (including studying, reading, writing, homework, rehearsal, etc.)?



n=21  
av.=5

For courses with laboratories only:



Please use the following to answer additional question(s) that may be provided by your instructor:

Instructor provided ranked question #1	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #2	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #3	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #4	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #5	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #6	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #7	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #8	The evaluation will not be displayed due to low response rate.

Prof. Nicholas Bertozzi (as private and confidential)

RBE 2001 - A01 UNIFIED ROBOTICS I: ACTUATION for 201801\_A

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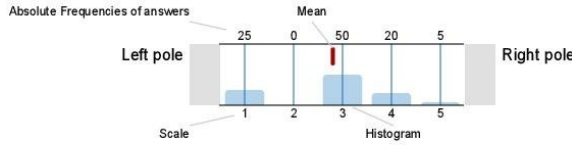
Prof. Nicholas Bertozzi  
RBE 2001 - A01 UNIFIED ROBOTICS I: ACTUATION (201801\_A)  
No. of responses = 11



Survey Results

Legend

Question text

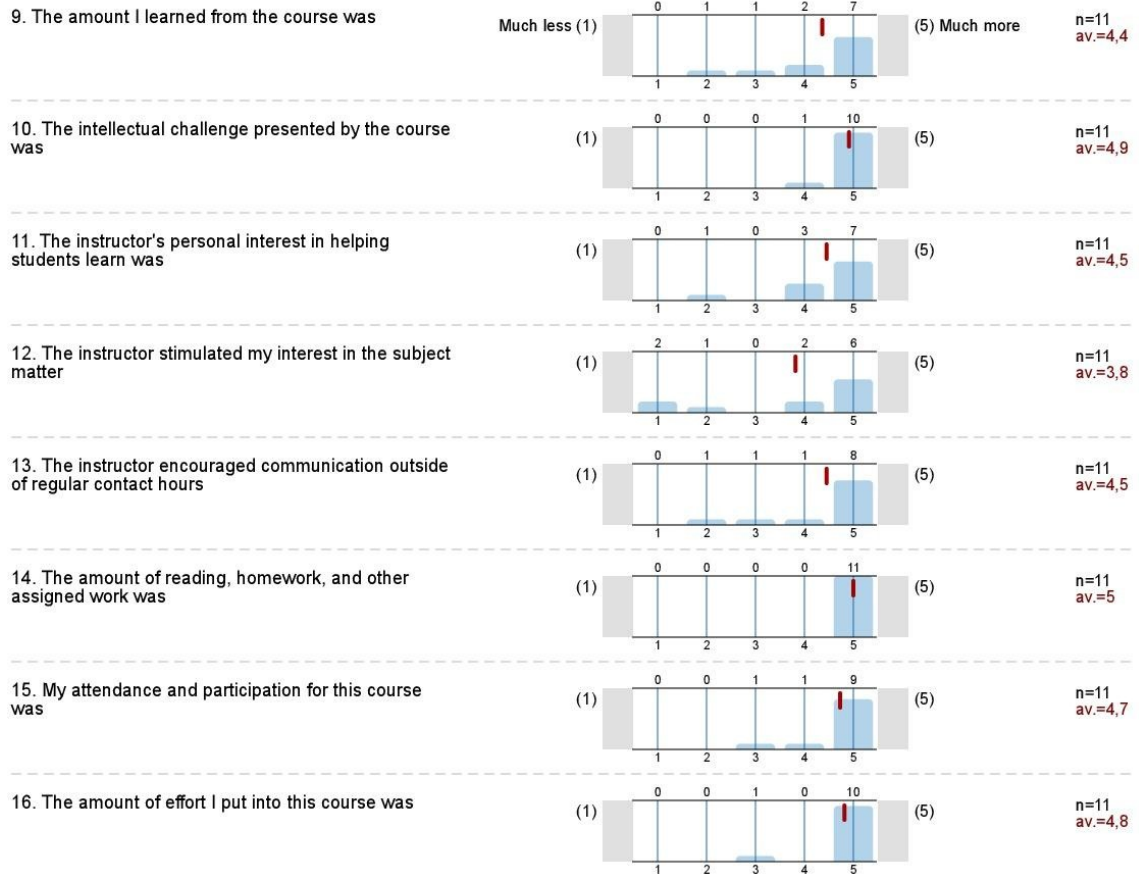


n=No. of responses  
av.=Mean  
ab.=Abstention

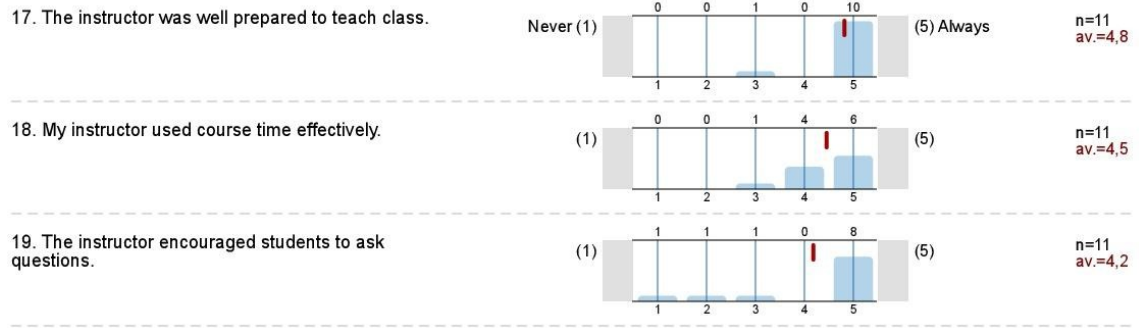
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1. My overall rating of the quality of this course is		n=11 av.=3,9
2. My overall rating of the instructor's teaching is		n=11 av.=3,9
3. The educational value of the textbook and/or assigned reading was		n=10 av.=3,4
4. The educational value of the assigned work was		n=11 av.=3,9
5. The instructor's organization of the course was		n=11 av.=3,9
6. The instructor's clarity in communicating course objectives was		n=11 av.=4
7. The instructor's skill in providing understandable explanations was		n=11 av.=3,7
8. The instructor's skill in speaking clearly and audibly was		n=11 av.=3,9

Relative to other college courses I have taken:

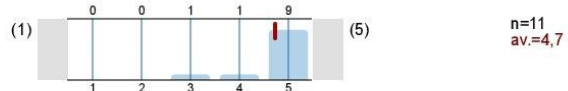


How frequently were the following statements true in this course?

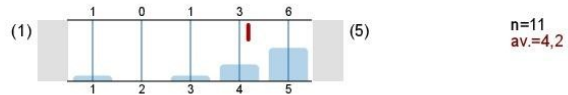




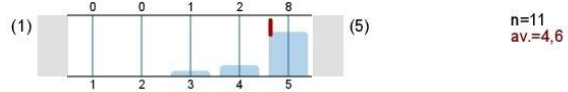
20. The instructor treated students with respect.



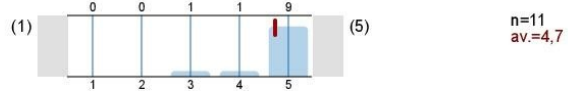
21. Instructor feedback on exams/assignments was timely and helpful.



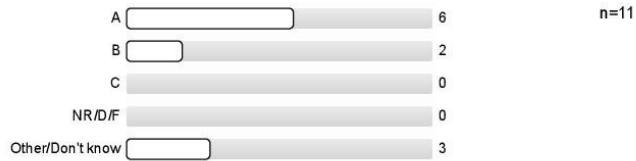
22. The exams and/or evaluations were good measures of the material covered.



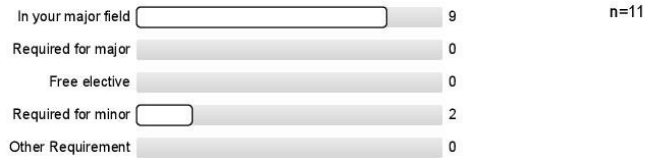
23. My grades were determined in a fair and impartial manner.



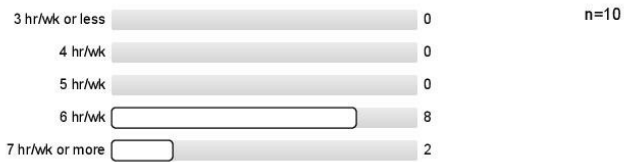
24. What grade do you think you will receive in this course?



25. Which of the following best describes the role of this course in your academic program?



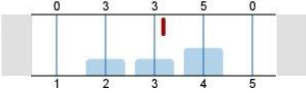
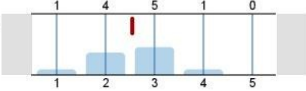
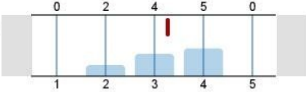
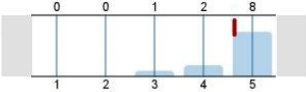
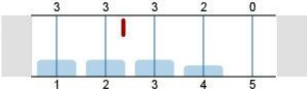
26A. On average, how many hours of the formally scheduled hours for lecture, conference, and labs did you ATTEND each week?



26B. On average, what were the total hours spent in each 7-day week OUTSIDE of formally scheduled class time in work related to this course (including studying, reading, writing, homework, rehearsal, etc.)?



For courses with laboratories only:

27. The instructor showed me how to use lab equipment properly.	Never (1)  (5) Always	n=11 av.=3,2
28. The lab and/or computer equipment was in good operating condition.	(1)  (5)	n=11 av.=2,5
29. Good laboratory procedures were emphasized	(1)  (5)	n=11 av.=3,3
30. Relative to other lab experiences, the intellectual challenge presented by the lab assignments was	Much less (1)  (5) Much more	n=11 av.=4,6
31. Relative to other lab experiences, the clarity and specificity of lab assignment objectives was	Much less (1)  (5) Much more	n=11 av.=2,4

Please use the following to answer additional question(s) that may be provided by your instructor:

Instructor provided ranked question #1	Low rating (1)  (5) High rating	n=1 av.=3
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Instructor provided ranked question #2	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #3	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #4	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #5	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #6	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #7	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #8	The evaluation will not be displayed due to low response rate.

## Comments Report

Your thoughtful answers to the following questions would be helpful to your instructor. (Please answer in the space provided underneath each question.)

What did you particularly LIKE about this course/lab?

- Good content, fun project.
- Great course, covered lots of material. Great projects, teaching, course structure.
- I enjoy the opportunity to apply what I am learning in a very hands-on, realistic scenario. Professor is incredibly patient and kind to students, and is willing to take as much time as needed to make sure an individual student understands the material.
- I liked the material that we learned in this course. I feel like I have learned a lot. I also really liked Professor Bertozzi.
- It covered a lot of groundwork that is important to a lot of engineering, I feel like I have a rough knowledge on a fair amount of fields.
- Taken individually, each one of the topics covered in this course was fascinating and important.
- The course is very helpful and informative. I think I learned a lot from it.
- The instructor really cared about the students and wanted to help them. Tons of TA/SA help available.

What did you particularly DISLIKE about this course/lab?

- I believe that for me, who this topic does not come easy to. The class was so fast and our work so difficult that I felt like I was not learning anything, instead i was just trying not to fail.
- I no longer understand the concept of free time.
- Lab materials were poor and sometimes not provided.
- So much material was covered in so short a time that it was almost impossible to keep up.
- The lab was not run well. Kevin Harrington (the lab manager) is certainly very experienced and knows what he is doing, however, the lab does not have the necessary materials for every team. Our team did not receive necessary tools to do the lab and often had to borrow from other teams when they were done with the lab, which caused us to spend a lot of time last minute trying to finish the lab.  
  
I also extremely disliked a lot of the SAs in this lab. They were not very helpful. A lot of them were often sarcastic and unclear when you asked them a simple question that you needed help with. The best SAs that were in this course were Hans and Keion. The TAs were awesome and very helpful.
- This class is possibly the most difficult class I have taken in my life, and unfortunately, that difficulty does not stem from the complexity of the material, but from the structure and content of the class. RBE 2001 suffers from the same problems as the other RBE core classes, in that it attempts to put far too much learning into far too short a time, at the expense of the students. Much of the difficulty lies in having to teach yourself a million small steps that weren't included in the instructions or taught in class for no particular reason (eg. being asked to export data in a certain type of file that no one has ever heard of, and having to spend an hour researching how to). This class and its exhaustive time commitment has been destructive to my physical and mental health, and has made it very difficult for me to stay passionate and enthusiastic about robotics.
- Were extremely unclear about what parts you could use, causing many teams to have to redesign very late into the term.
- my team had so much problem with the lab. There were missing pieces in the kit, as well as broken parts that cost us many unproductive hours in the lab.

Can you suggest anything that the instructor could do to improve the quality of teaching?

- Cut out some of the fluff in the lectures and do more examples
- I know that these requests are difficult given your mach speed schedule, but if we went a little slower and really tried to cement the topics we covered, even if that was just a brief recap a day or so after we covered the material. If that is too difficult, I think more engaged learning, similar to the quizzes, could both boost understanding and grades for me at least.
- Labs and instructional material should be more extensive and instructive- specific details on how to use certain lab tools, file types, download certain softwares, and even just more information on specific formulas should be provided somewhere for students (lab appendices and the RBE wiki attempt to fulfill this, but fall short). I also wish the professor was more encouraging and less objective when it comes to helping students learn. If a student has clearly put an enormous amount of time and energy into something, they should be at

least verbally if not academically rewarded for it.

- More focused lectures - you can't teach it all, and just because you went over it on one slide doesn't mean the students retain it. Set pinks gives on what you want us to learn from each lecture and then trim the presentations down from there.
- Professor Bertozzi moves WAY too quickly in class. It would be helpful to slow down. It would also be helpful to give us more time on in class surveys as I tend to take a little longer figuring out how to solve a problem. The videos are very helpful in learning new programs that I was not previously experienced in.
- Reduce quantity, improve quality. Spend more time on each topic and go into more detail. Skimming over a topic quickly is as useless as never covering it at all. Skimming over a dozen topics is useless - going into depth on four topics is extremely helpful.
- The labs could be a lot more clear.

Would you encourage a friend to take a course from this instructor? Why or why not?

- Absolutely
- I think so, I would just recommend them to know what they are going into. This class was incredibly difficult, I do not know if I have the stuff to take another robotics class after this one, but I do not hold the instructor responsible for that.
- I would not encourage anyone who enjoys robotics or who does not have incredible emotional fortitude to take this class. I have had to drop all of my extracurricular activities and loose a significant amount of sleep in order to scrape by completing labs and assignments in this class. This has damaged the balance of my life, and decreased my enthusiasm for the subject.
- If the lab is better organized. Yes. Otherwise, if it's not required, no.
- Yes, I would. Bertozzi presents the syllabus well, and is very willing to accommodate students.
- Yes, as long as they don't mind dedicating all of their time to it.
- Yes. Professor Bertozzi is an awesome professor! He is always in his office and willing to help, replies to emails in a timely manner, and is willing to give 110% to help any student learn the material. Professor Bertozzi goes out of his way to make sure students get the help they need in this course. If you need an extension, Professor Bertozzi is very understanding that there is a lot going on in our lives and will give you the time that you need. He is a very caring professor. He also is very keen on making sure we learn the material (which is why he would give us a lab extension, to make sure we can finish and learn).
- Yes. Professor Bertozzi was extremely helpful and kind every time I talked to him. He is very enthusiastic about helping students. He is probably one of my favorite professors.
- Yes. Professor cares about the class and the students.

Prof. Nicholas Bertozzi (as private and confidential)

RBE 2001 - A02 UNIFIED ROBOTICS I: ACTUATION for 201801\_A

Dear Prof. Bertozzi,

As part of WPI's student course report process, the quantitative results for each course section are distributed by email. These results will also be accessible on the Web Information System (Banner) under Faculty Services. The completed questionnaires are being returned to you via department mail. Students' written comments can be found on those forms.


This email contains the results for RBE 2001 - A02 UNIFIED ROBOTICS I: ACTUATION.

The responses to each question are shown in a histogram, with the number and average values of responses shown to the right. Please note that the number of responses listed in the header section of the report reflects the number of evaluations scanned. Since some blank sheets may be scanned, that number may be larger than the number of respondents.

If you have questions about the scanning of your student course report data, please contact Art Heinricher, Dean of Undergraduate Studies, at [heinrich@wpi.edu](mailto:heinrich@wpi.edu) or x5397.

The Morgan Teaching & Learning Center website offers some suggestions for interpreting student course reports ([www.wpi.edu/academics/morgan/interpreting.html](http://www.wpi.edu/academics/morgan/interpreting.html)). If you would like to discuss these results confidentially with a colleague, please contact Prof. Chrys Demetry, Director of the Morgan Center, at [morgan-center@wpi.edu](mailto:morgan-center@wpi.edu) or x5707.

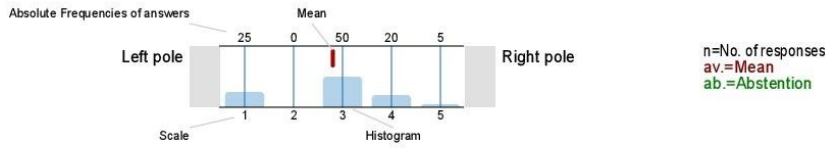
Prof. Nicholas Bertozzi  
RBE 2001 - A02 UNIFIED ROBOTICS I: ACTUATION (201801\_A)  
No. of responses = 15



Survey Results

Legend

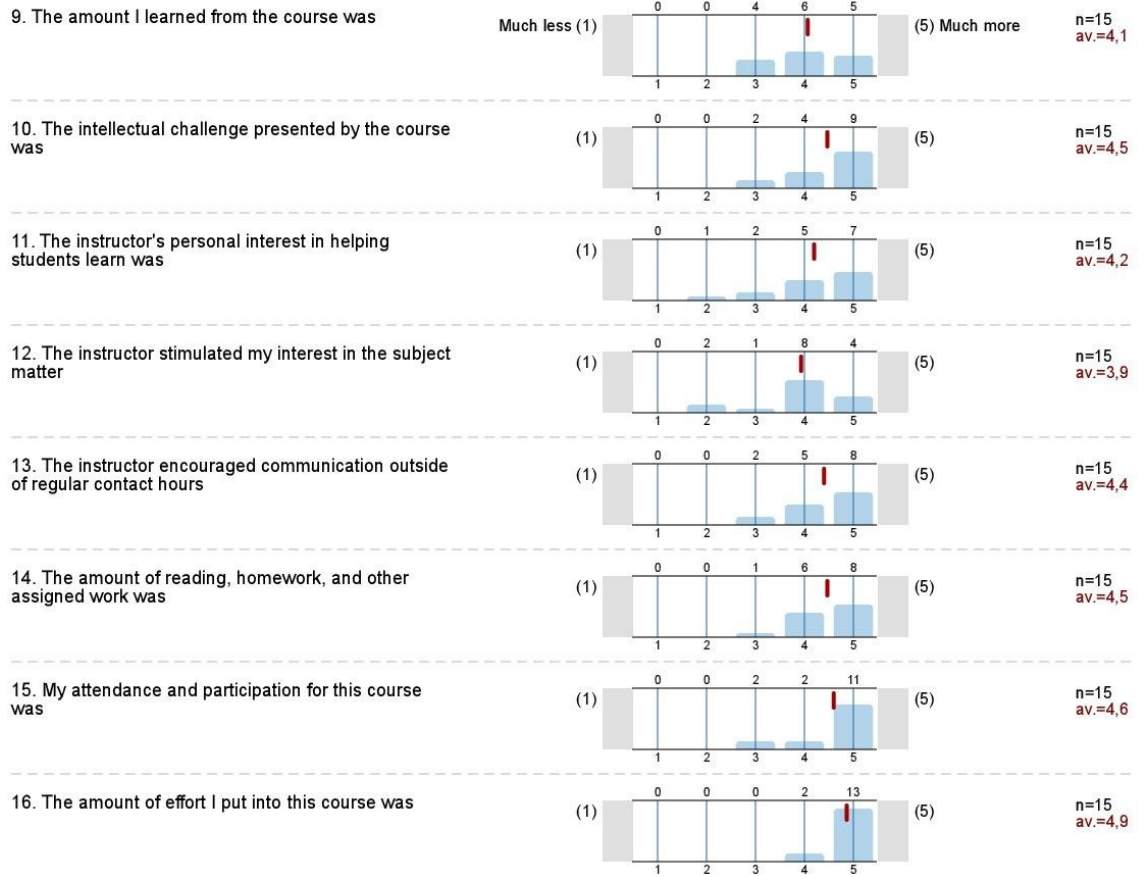
Question text



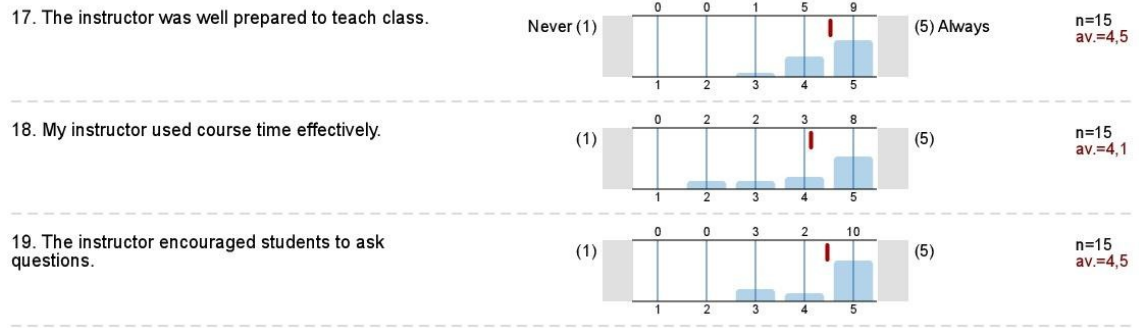
You can help improve the quality of teaching at WPI by providing your responses on this form. Please consider each reply thoughtfully. These reports are used by the instructor for self-improvement, by students during course selection and by members of the administration and faculty committees. Your responses are anonymous and optional. Your comments will not be returned to your instructor until after the grading deadline.

1. My overall rating of the quality of this course is		(5) Excellent	n=15 av.=4
2. My overall rating of the instructor's teaching is		(5)	n=15 av.=3,7
3. The educational value of the textbook and/or assigned reading was		(5)	n=15 av.=3,3
4. The educational value of the assigned work was		(5)	n=15 av.=4,4
5. The instructor's organization of the course was		(5)	n=15 av.=3,7
6. The instructor's clarity in communicating course objectives was		(5)	n=15 av.=3,7
7. The instructor's skill in providing understandable explanations was		(5)	n=15 av.=3,9
8. The instructor's skill in speaking clearly and audibly was		(5)	n=15 av.=4

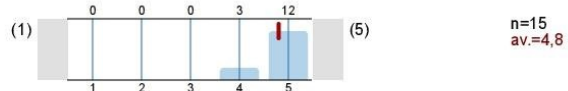
Relative to other college courses I have taken:



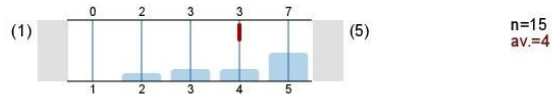
How frequently were the following statements true in this course?



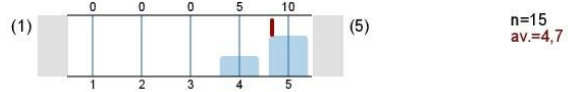
20. The instructor treated students with respect.



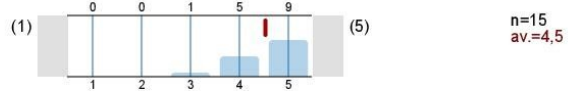
21. Instructor feedback on exams/assignments was timely and helpful.



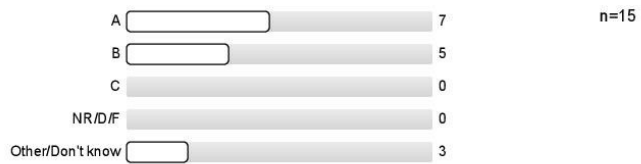
22. The exams and/or evaluations were good measures of the material covered.



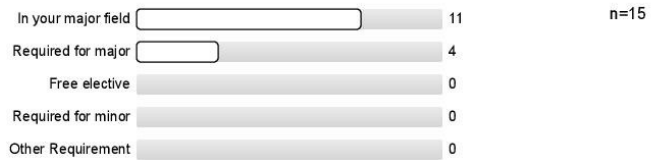
23. My grades were determined in a fair and impartial manner.



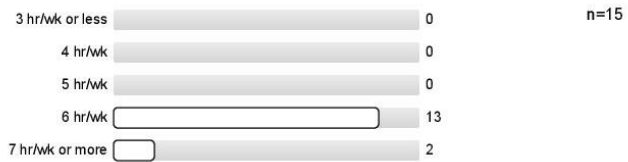
24. What grade do you think you will receive in this course?



25. Which of the following best describes the role of this course in your academic program?



26A. On average, how many hours of the formally scheduled hours for lecture, conference, and labs did you ATTEND each week?

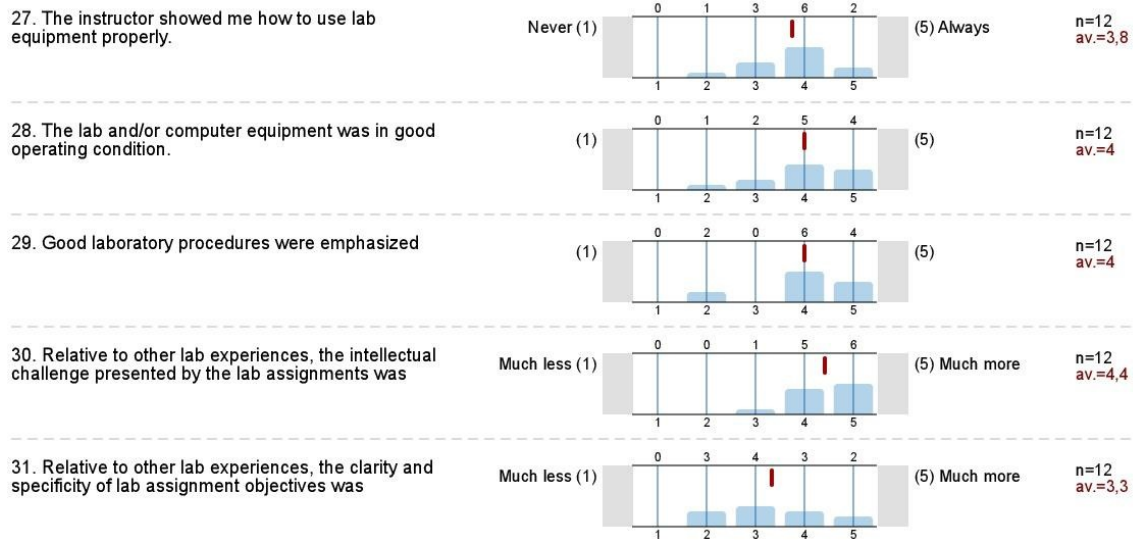


26B. On average, what were the total hours spent in each 7-day week OUTSIDE of formally scheduled class time in work related to this course (including studying, reading, writing, homework, rehearsal, etc.)?





For courses with laboratories only:



Please use the following to answer additional question(s) that may be provided by your instructor:

Instructor provided ranked question #1	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #2	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #3	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #4	The evaluation will not be displayed due to low response rate.
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Instructor provided ranked question #6	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #7	The evaluation will not be displayed due to low response rate.
Instructor provided ranked question #8	The evaluation will not be displayed due to low response rate.

## Comments Report

Your thoughtful answers to the following questions would be helpful to your instructor. (Please answer in the space provided underneath each question.)

What did you particularly LIKE about this course/lab?

- I enjoyed the weekly quizzes
- I liked that we went over examples in class and had survey questions to let us attempt the problem before going over the right answers. The instructor was also very available and quick to respond to emails.
- I really liked the amount of information I was able to learn during the course since it covers such a wide array of topics in a 7 week term
- Interesting course, a good step up from 1001.
- Personally, this class has been my favorite class at WPI and you are my favorite professor. Your ability to explain any question that was asked in a simple and understandable way was amazing. I really hope to take many more classes with you. Anyways, thank you for an amazing class
- The course was good as a project based course and applying the information learned in class to our actual robot. Help sessions with SAs were very informative.
- The final project is really fun
- The information was excellent for the development of understanding robotics and actuation and I was excited to learn. The pre-quiz help sessions are amazing
- The labs were very engaging.

What did you particularly DISLIKE about this course/lab?

- A large majority of the skills learned in this class were learned outside of class with no assistance from the professors or SAs. We were warned in the beginning that 90% of learning would have to be out of class, but the warning didn't make up for the fact that the learning took much longer than it needed to take. Personally, I learn from being shown something, so having to repeatedly fail at a task did not help me learn at all. This led to much of a time sink, reducing the time I could spend for my other classes and my outside life. My physical/mental health has declined due to this course.
- I wish the objectives are more clear. Especially grading rubric for Labs. Some TAs are harsh grader
- Lecture did not teach me nearly as much as it should've and I often left lecture feeling like I learned nothing or was more confused than when I walked into class. I wish class time was used more effectively.
- Often times the labs were not updated making things difficult. Also at times there was either a lack of materials or materials were taken making labs difficult.
- Resources and examples for help with homework, exam preparation etc, were often hard to find.
- The amount of time the labs would require outside of class
- The professor was inaudible for many of the lectures, the SAs were not very helpful during the labs with the exception of a few occurrences. I was explicitly told multiple times to "google it" when I had a problem in the lab. I spent too many hours outside getting work done that could have easily been helped if an SA was willing to spend a few extra minutes explaining something.
- We wanted to do a carriage system and didn't learn how to do it until the end of the design process ... basically a lot of the relevant mechanical analysis that we needed was taught after when it would have helped our design process, which is a bit frustrating, because we don't get a chance to implement it.
- You cannot give people labs with consistently missing materials. We were missing some parts from our kit and for one of the labs, the lab manager gave us the wrong motor, which we then had to use to complete the lab. There was also a huge amount of miscommunication with which parts will be available for the final lab robot. Especially concerning the motors, where we were not informed that we were not able to get more than 1 vex motor. Also the parts that had to be 3D printed by the lab (such as the coupler and gears for the Pololu motors) had no dimensions once imported to Solidworks. The lab manager used a program other than Solidworks to make the parts, which would be fine if the parts imported correctly to Solidworks so that we could use them, but they did not. The lectures themselves were hard to follow at many times. It seemed that the professor assumed we had more prior knowledge than we did, leading to him using terms that we did not know.
- Labs were very unorganized and the materials we would NOT be given for the final project were not clearly outlined. In addition things that were being given to us we were not made aware of until things were extremely close to deadlines

Can you suggest anything that the instructor could do to improve the quality of teaching?

- Better lab management and organization  
make sure every lab kit is given what they need for the labss and make the lab objectives clearer  
Let people know what parts from the RBE lab they will be allowed to use
- Better management and organization of lab equipment. More specification of the parts available for the final. Better sense of where the students are knowledge wise in the lectures. A lot of stuff made more sense once explained more clearly during the help sessions.
- Have SAs that are willing to spend extra time to help people. Speak louder
- I personally found the coding shown in class not very effective and would prefer to have that part of the course taught through a video. This way more time can be spent on the mechanical, electrical parts and we can have more time for questions about the final project, as well as more time
- Spend more time teaching how to do things for the lab.
- Take more time to go over problems in class instead of flying through the examples and then spending most of class looking through things on a tangent. In a given class period you would cover all of the topics necessary but the amount of time you allocated to each topic was very different from the amount of time each topic needed.
- Update all previous materials.
- Upload lectures before class starts so that they can be followed along on laptops. Also upload a separate version that has all of your annotations and drawings from class on it.
- When using your cursor to point at stuff, make the cursor more visible, because from the back it's hard to see what you're motioning at. Or use a laser pointer.

Would you encourage a friend to take a course from this instructor? Why or why not?

- ABSOLUTELY!!! Great professor, knowledgable, ALWAYS there to help the students and shows personal interest in the students' projects.
- I'm honestly not sure; Professor Bertozzi was extremely nice and helpful when you went to him during office hours and he tried to accommodate all schedules in his office times, but his lectures were extremely different from my learning style so I struggled a lot.
- Yes because he is very knowledgeable, but no because the lectures are boring and not very helpful.
- Yes because this course is very important.
- Yes, because he is really helpful and willing to help
- Yes, he's very invested in students understanding the material and is open to any and all relevant questions to the course or final project.
- Yes, overall informative course and very enjoyable. Only downside is the labs are annoying at times with all of the miscommunication.
- yes if they like robotics only

## Appendix F: Faculty and Staff Interviews

Prof. Nicholas Bertozzi Interview - 2/8/2018

JR: What is your name?

PB: Nicholas Bertozzi.

JR: Are you okay with this interview being recorded, transcribed, included, and quoted in our IQP report?

PB: Yes.

JR: How long have you been a professor for RBE 2001?

PB: Since January 2016.

JR: Are there any complaints or points of frustration that are frequently expressed during your office hours?

PB: Frequently expressed...

PB: The most common complaint I hear is the pace and the amount of stuff we have to cover. With students being required to do labs every week, homework, and a significant project... The workload is the number one thing I can think of off hand.

JR: Are there any aspects of the course that have particularly poor student performance overall?

PB: Well I think probably the biggest problem is students getting all of the software integrated to work as one complete unit. Some teams to do that beautifully but probably I would say fifty percent struggle with it.

JR: How do you feel about the labs overall?

PB: So there's a lot of different things covered in the lab and some of the stuff we don't cover in class, but my understanding when I came here was the philosophy of the department was that they want students to be able to learn how to teach themselves and get information themselves, which I think is great, but I think it can be too much, at times.

PB: There's definitely more than two hours worth of work to do in those labs.

PB: There again, what I was told was that that's the expectations that they're not going to be able- we have labs that the students aren't expected to be able to finish in that amount of time, I'm not sure if other courses, I'm assuming that other courses here don't have that philosophy that, you know, like if you take a physics lab you're expected not to have to come back and spend eight more hours in the lab trying to finish collecting your data obviously you spend time out of class writing it up and, you know, finishing equations also.

PB: But, I don't think any of these labs, I don't think I see anybody finishing them in two hours let alone from finishing the work to do the labs.

PB: From what I've been told and again they put together a great program here that a lot of people have put a lot of time and effort into bringing this together, is that that's the nature of robotics, its multidisciplinary, there's a lot of stuff you have to learn and be able to not necessarily become an expert but grab the stuff you need to know so you can solve the problem.

JR: What do you think a lab looks like from a student's perspective?

PB: I think there are some students who kinda do fine with it, but they're in the minority. To most students I think the amount of material is overwhelming. That's just my impression.

PB: Although like I asked the class today how things are going and they didn't seem too bad with it, it felt like yeah it was a lot of work but they seemed to be doing okay this term, keeping it up so.

PB: I don't think I've had anybody come into my office so far this term to complain about the workload.

PB: Well we have already been implementing some of these suggestions, you know, trying to have more more video available. more explanation of... Trying to reduce the frustration still a lot more to be done and I think they already see that it's a little bit better they're getting a little more help.

JR: What do you think a lab looks like from an SA's perspective?

PB: So I think that my impression is again this is more my impression from things I have ever talking about or some of the questions asked me.

PB: I think that there are some of the SAs, especially the ones who are seniors having been SAs for this course for awhile feel very comfortable with all the stuff.

PB: But I think that some SAs, for at least their first year, there may be some of the things that they really understood well but there are other things that they didn't understand as well so I think it's a little bit harder for them to explain those to students

PB: That's just an impression nobody has come up and said to me, "I don't really understand such and such", I take that back, some have come to me and asked me how to do something that they weren't positive they knew how to do, so.

PB: But for the most part I think they have a pretty good handle on what to do.

JR: What opportunities for improvement do you see in the labs?

PB: So, again from what I've heard from you guys and from one student told me that all.

PB: Well, so Professor Stafford's philosophy is that everything that he does including the homework is going to be directly related to the project.

PB: And the labs clearly are directly related to the project.

PB: I think there is a lot of relationship to what we try to accomplish in turn terms of learning outcomes in the labs that they can apply to their project or maybe not as directly.

PB: But then we also do a lot of little things that I think are interesting.

PB: Like actually seeing how fast you can switch a transistor or regular relay with an electromagnet.

PB: So that's interesting or trying different analog read or digitalwrite, analogwrite and all see how that takes different amounts of times.

PB: Or like in this lab coming up with lab 4 we're using an H-bridge

PB: And they're going to first run some tests with a function generator and try different frequencies and see how it reacts, I mean, that's all great stuff, but it's not something gonna not gonna be trying to figure out what frequency use when they drive their motors for their project.

PB: Right they have a controller they know what they're gonna do.

PB: I think there are pieces of the labs that obviously do not apply directly.

PB: I don't think anybody's using transistors in their projects, or that big relay.

PB: So I don't know, that stuff is interesting, I guess the question would be should we count on the other supporting courses like in ECE to cover that kind of stuff.

PB: Or do they cover that kind of stuff?

PB: So.

PB: I think that what you guys doing in terms of looking at the whole picture here is really important.

PB: And then we can, moving forward, we want makes significant changes to the labs, we can or we can propose that to the course directors.

PB: So I'm trying to remember the original question, what changes do I think need to be made?

JR: The question was, what opportunities for improvement do you see in the labs?

PB: Okay so I think additional video support or like how to use lab equipment.

PB: If we want students to use LabView and Python.

PB: Some additional resources for that.

PB: And we have to do a better job of actually reinforcing that learning.

PB: Making a part of the lab of where they actually do something more than just load it or connect it to the Arduino or something.

PB: But again I guess the trick is there's so much content how many things can we accomplish before the students are just overloaded.

PB: I think there is still some frustration in the labs in terms of getting stuff to work.

PB: Well that's not exactly unusual either.

PB: Usually even when you take physics a lot of the time, these are pretty common rote experiments that you do in physics, there's still a lot of times the equipment is not working right either.

PB: But I think we can still do better on that maybe if we switch to, depending what platform we use, maybe it has built-in wireless, something like that might.. Bluetooth seems to be an ongoing issue.

PB: So I haven't heard a lot of people having problems but I know at least a couple people who have it working.

JR: This might be a little bit similar, but what results do you see coming out of the labs?

PB: You mean in terms of student learning?

JR: Yes, the student experience.

PB: So I think in general the stuff they turn in is pretty good.

PB: But there is a question, and I mean we still have like the final exams is worth twenty five percent of their grade, for instance, that's totally on your own.

PB: Because I know that some students have told me that the only way they could get through the course was to split up the work on the labs so like one person would work on one thing another person or another.

PB: And again the problem with that is that not everybody is learning all the different parts...

PB: So I think that in general, the their grades on the labs are or I mean the stuff they turned in in the end whether with help from an SA or from specialization.

PB: Is pretty good, it's not bad.

PB: I mean I think that the work is, in general, pretty good.

PB: Okay.

PB: But again I guess you know with some students tell me they had to drop out of the different sub- you know they were the band or they were in theatre or something and then this term... they you know, that's a comment I get at the end of the term, that "Yeah we we got through it but it really cost us in other ways".

JR: So, moving on to the lectures, what are the strengths that you see in the lectures?

PB: Yeah I think that we do cover a wide range of material.

PB: That I think for the most part is all important stuff.

PB: And I'm assuming you're going to follow up with the question what is the weakness?

PB: Can I get to that one now?

PB: In a course like this at my other school was a design course and it wasn't...

PB: And yet they did have to combine some electrical stuff with mainly mechanical.

PB: But I actually had the registrar schedule extra hours, which I just called recitation, so that I could spend more time. The educational research shows that in fact you mentioned in your draft that this idea of a flipped classroom.

PB: That having students look at stuff and then coming to class and work on stuff in class with guidance so that instructors work, I think they said an instructor should be a guide on the side, rather than be a sage on the stage, right that just lecturing people is one of the most inefficient ways possible to learn.

PB: And so I would say the weakness that I feel right now in 2001 is, I spend too much time lecturing.

PB: Because we gotta get through the material and really what I would rather be doing is giving students more time to try stuff and I try to do that a little bit.

PB: Yeah I guess it's been exacerbated this term because I've had to fly through so much stuff because Thursday is the last lab.

PB: So now I feel like we've covered that material and now I can start taking more time in lecture. There's actually like four review sessions I think until the end of the term, which I probably won't be able to use all of them because I've gotten a little like half a class behind, and now I'll be able to spend more time presenting something and then having students work in groups to do the canvas quiz and see what they got, and if a lot of people aren't getting it have them try again.

PB: You know that kind of stuff, it's more like the kind of stuff.. Did you all have Professor Stafford? For 1001?

PB: So I mean he tries to do a lot of that stuff and its more fun for the students, they're more engaged. I can just look in the back of the classroom like the row in the back everybody has their laptops open, I'm assuming they're not looking at my lecture. Maybe they are. But I don't want to waste their time. So I would say right now the biggest weakness is there's too much straight lecturing. Which is fun for me, I mean.

PB: But I know this from, I go to conferences and that kind of stuff like that and have to sit and listen to somebody else talk, it's a two hour talk or something? I realize, I'm like, "Wow, this is- this isn't easy to just sit and listen to somebody for two hours", you know, you want to do something, try something.

JR: This might be a little bit similar but, what results do you see coming out of the lectures?

PB: I think students normally do pretty well on the tests and I think part of that is because of the review sessions.

PB: Where they actually now take the time to try more of the problems.

PB: But I would say in general im usually pretty happy with, like, on the final exam, the kind of work the students can do. I think a lot of them did understand it in the end. I think it could be a lot better.

PB: With a more active classroom, that's something I want to try and figure out how to do.

PB: Part of it is having people watch more stuff outside of class, but again like some students were telling me the last time that there was too much to watch. There's the prelabs, they're expected in some of the homeworks to watch the video, like on the four-bar analysis, and they have all the stuff they have to do.

PB: But I think I can add a little bit more stuff also maybe try and condense some of it.

PB: That's the goal, have it be a more active classroom. Even like the stuff we toda, we did PID, Brad came, and I did like about a half a lecture on theory.

PB: And then he did the rest of the time doing different stuff with the ultrasonic sensor and the gyro and changing the PID gains and seeing how it affected- it was very visual.

PB: Makes it so much easier to understand.

PB: So we we want work this summer and try to figure out more hands-on things we can do in class.

JR: Okay.

JR: What strengths do you see in the final project?

MC: This is the last section of these kind of questions by the way.

PB: So I think it reinforces stuff they learned in 1001.

PB: In this project they have to do a complete solid model of the robot and explain all the.

PB: Like the position synthesis they did in terms of how they figured out where they want their thetas to be, they have to do a complete force analysis on joints and moments, torques required.

PB: They have to do, most of them do line following.

PB: So they get to try that again.

PB: Yeah I think of programming obviously is very very.

PB: It's hard to get through but it's I think it's a good experience for them to have to put together that complete of a package.

PB: So, follow up question, what weaknesses do you see the final project?

PB: We have them do all these calculations but they're pretty much meaningless because it's gonna work because the thing they have to pick up is so light.

PB: Speed isn't important, they have lots of time.

PB: Ten minutes to move across a little field.

PB: So while.

PB: I would.

PB: As we talked about, I would like to up the level of difficulty of the mechanical, the actuation part so that they have to learn more about actuators and their limitations.

PB: And how to design them efficiently.

PB: So you know.

PB: I mean some of the designs are pretty good at some of the stuff some of the four bars...

PB: It works, but it's not.

PB: They didn't necessarily do it the best way.

PB: Or the efficient way to do it.

JR: Right, so, what aspirations do you have for the final project?

PB: Well I mean I think we've had this final project for a while, I think parts of it are good.

PB: But the actuation parts of it can be improved, so that's what I would like to see more of.

JR: Okay.

JR: Now the last question on the final project. In regards to the current final project, what results do you see coming out of the final project?

NG: Again from like a student achievement and learning-

PB: Yeah. I would say I'd break it into thirds.

PB: Where one third of the students, one third of the teams produce amazing robots. They look nice, they're functional, they worked really well.

PB: A lot of the time they're very creative, like did you see Max Westwood's?

PB: That's when I showed a video of his team's ... so it actually had, you know that film advance mechanism?

PB: So he actually did that to get the tube. So it's really nice because you just have like a V-trough or something you have this rubbery thing so you don't have to be perfectly lined up and it worked really well.

PB: And then some of the students buy other components and they have slave boards or...

PB: You know, they really demonstrate that they have a team with an ECE major, a ME double major, and another person is a CS double major. Some of the things they do I think are really impressive.

PB: And then you have like the middle third which basically gets it to work with some pain and struggle. It's not perfect but they accomplish the task, right? And then there's the other third that

PB: In some cases they just really struggled in their work, sometimes they got too late to start and waited too long.

PB: In other cases they reach too high, which is okay but the the rubric is ruthless, right? You gotta be able to do it, so like some of these teams are last term there was two teams learning so they had built a complete track on the.

PB: You know some of the stuff they did was really light or do you guys know Xavier?

PB: Well so like the one that that his team did, I think he's dual mechanical?

PB: It was reaching too far because there are problems you run into trying to do that.

PB: Or are really hard in terms of tolerances and you know... anyways so either they they didn't but I don't feel bad about those because they tried and they did get some measure of success, I feel bad in the sense that they feel bad because they couldn't in the end, get it to work the way they wanted it to, and they just ran out of time, right?

PB: But I would say that in the lower one third, those are probably the exceptions.

PB: So I'd say that the lower one third, which they're still good students, all students at WPI, it's not easy to get into here, you have to be a good student.

PB: Usually there's a team where there are just too many slackers on a team, to be honest, and I don't feel bad about that usually its own maybe one team a term.

PB:

PB: But then the teams where they really try but just felt overwhelmed.

PB: There's usually probably four or five teams, four teams maybe like that, I always feel bad about that. Because it wasn't that they weren't trying, it was just too much.

PB: And usually the part that was too much was the programming.

PB: Yeah in some cases they didn't get the mechanical part working in time so they could start programming until there's like a week to go, its just, it was too late.

JR: Okay.

JR: In conclusion, is there anything that you feel we did not ask, that you would like to be known on the record?

PB:

PB: So I think I think this is a.

PB: You know, again I'm the new guy on the block.

PB: You know, when they first talked about this program ten years ago.

PB: I guess a number of factors here said there's no way, you can't make it work, its too much. It's ECE, it's CS, it's ME. Even one of those things by themselves is already hard. You can't make it work.

PB: They made it work.

PB: There are people that obviously, they're graduating, they have the highest salaries, starting salaries from any major here.

PB: And my question is, and I've asked you guys this before, is that because the only students who will even attempt this are already so motivated and so hard working and great and so smart, that it doesn't matter what we do, they're going to be successful anyways?

PB: Just because that's just their nature.

PB: Or is it because the curriculum is so good?

PB: And I imagine it's some combination of both.

PB: I haven't been here long enough to really know.

PB: But I just wonder about the ...

PB: This constant pressure to just keep moving and never having time to review so.

PB: I mainly do 2001.

PB: 1001... It's the same thing but it's more of a first taste of robotics, that course or, you're not expected necessarily to master all that stuff, more to get a taste of it. Do that do the best you can with it.

PB: But by the time you get to this beginning, you know, sophomore year and you should really master this stuff.

PB: And I don't know how people get through it.

PB: In terms of all the different stuff we need to do.

PB: And yet students do get good at reading spec sheets, teaching themselves how to do things, learning how to use a piece of software, or going online and teaching themselves something. You see this in MQPs especially.

PB: And that's really valuable in industry.

PB: People in industry, the managers in industry, they want engineers that can describe what the problem is, or help describe what it is, and formulate a problem statement, and then they don't have to babysit them, they want somebody who is self motivated and can find out what they need to know. This program certainly prepares people to do that.

PB: But.

PB: A great course to some students, some students fail the course, but I don't know what the answer is to that because of the multidisciplinary nature of it. Its true to the faculty even.

PB: How do you hire someone who's...

PB: Well I mean there are a few people here like Bill Michaelson.

PB: Who just have an amazing breadth of knowledge and expertise.

PB: But there's not many people like that.

PB: So you hire a CS person and they scramble to try and learn, in an integrated course, the other parts. I've talked to other faculty, new faculty and stuff... It's the nature of the beast.

PB: So what I guess the question was, is there anything else that I want to go on record as saying. I guess I would say, this is gonna be a very dynamic program because things are changing so fast.

PB: So we will have to keep looking at, we only have so much time, what are the most important things for people to know?

PB: It may be that some of the stuff that we do that's more basic science type of stuff or at a lower level of understanding. By low I don't mean it's easy to understand.

PB: We have different stuff in electronics and vision systems or whatever, as the systems get more sophisticated that you can buy, it's more important than you know what the limitations are, how do you implement it, how to use it effectively, and whether you understand everything about the physics or the mathematics of what's going on inside that thing, right?

PB: So.

PB: I still feel the situation in 2001 is, I just wish I had more time for the students to work in groups, to review stuff, so that they really feel like the understand the material.

PB: In the end it does seem like at the final, most of them do okay.

PB: Sorry, I guess I'm babbling at this point, I mean it's a very tough difficult question because it's been a successful program and now across all over the place there's robotics programs springing up. Which really makes it hard for WPI because people keep snatching away our faculty away. Probably with big offers of a big new lab, and a higher salary or whatever. Big schools have a lot of money.

PB: So I think it's really exciting, the work that you're doing, we can change the project, we're looking at a new platform, we're going to be moving to new labs.

PB: So it's a pretty exciting time.

JR: Alright, thank you for your time.

PB: You're welcome.



## Prof. Bradley Miller Interview - 2/8/2018

NG: All right so just for our records could you state your name?

BM: Brad Miller

NG: And are you okay with this interview interview being recorded, transcribed, and possibly included in our report?

BM: Yes.

NG: Are there any common complaints expressed during office hours, and what are they?

BM: ...Not during office hours which intentional complain about the about the sequence of courses. Sometimes a lot of difficulty sometimes about the continuity. Sometimes the labs. Where, the lab equipment you know, parts missing. you know a lot of equipment not working you know that kind of stuff.

NG: At this point in your recall any more specific details and any of those subcategories.

BM: Well like the three thousand one arms. That we did didn't work.

NG: We're mainly focusing on like 2001.

BM: Oh, 2001, Bluetooth. 2001, there's been a problem because the bluetooth chip, the bluetooth modules often don't work there's problems with pairing.

BM: The Bluetooth setup wasn't set up for the final project. So the board a lot of stuff never got set up so last term. And and people had other problems.. Because... I guess that's most of it.

NG: Are there any aspects of the course that are particularly poor student performance overall.

NG: And if so what are they.

BM: I'm not sure. I hear the students have a lot of trouble with the bluetooth chips. And I don't know about the rest because I don't actually.. Being the guest lecturers. I don't actually see other stuff. But that's one that I hear about, that I have some influence over.

NG: How do you feel about the labs overall?

BM: Ya kinda again I can't I'm not exactly sure, I know what the programming parts....

NG: You can focus on those.

BM: Yeah I.

BM: I'm not sure, I'm not sure, I mean I like the final project, I like the solutions that I - I like some of the very creative solutions that I see for the final project, that people do.

BM: I'd like to be able to keep it that way so that there's opportunities for students to come up with very creative solutions and kind of you know think outside of box you know the guys that do stuff like robots with no wheels that have something that drives up on a track or something, are a pretty cool solution. That you know, you wouldn't think about.

BM: So I want to be able to maintain, keep the labs in such a way that that is maintained.

NG: So moving on what opportunities for improvement do you see in the labs?

NG: And you can talk from mostly like a CS perspective.

BM: Well clearly you have to get the equipment under control I mean the lab stuff is, people are using, you know people can't find shaft collars because other people are using them for spacers, or something, I don't know, because they couldn't find spacers, or whatever. You know it's pretty bad. I mean you are spending sixty thousand dollars, to come here for a year and you can't find shaft collars for your robot. You know, that's kinda crazy, that you can't do that.

BM: And you know there are other parts that are kind of kind of like that so... I think we should really try our best to keep the labs smooth and really work. We shouldn't we shouldn't be exposing all these issues that you know that, arrive from maybe poor testing of the labs. Or poor limitation of some of the software or the other things. We shouldn't be inflicting that on the students in the class. I mean, the problem they have is hard enough. Without having to make it work on hardware or software that doesn't work. And and so on I think... what we really need is make a study much... smoother. You know what I mean.

NG: Mhmm. What results you see coming out lab and this can be either from like currently or what you would hope the results to be.

BM: Well I mean I see that I I like I said it's very very cool creative solutions and indicate that people have you know that students have a ... real interest in solving the problems, a real interest in the class and the labs. And it's not. I I don't know what happens in physics labs but I doubt that it's what happens here. You know that people do the lab they get in get out. They write up a report or something and that's it. But, We're over here, students are almost competitive you know with a sense of pride trying to make their robots better than anyone else's and, and that's, that's pretty cool, I think that's unique. I think that's pretty unique. Well I don't know you guys take more classes than I do. I mean.. I think that's pretty unique in robotics. You know, that you don't really see anywhere else were people where students try. You know. They're making like laser cut parts and 3D printed parts and machining parts. And stuff like that just to try and make the robot. You know. Display case worthy. And and I don't think that happens anywhere else and I think that's that's pretty good.

NG: What strengths and weaknesses do you see in the lectures and you can kind of focus on CS lectures?

BM: Well like everything I think there's.. there's.. we're trying to pack a lot of stuff into..a few classes. And so I think that there is not always adequate time to cover the material and and maybe they're not adequate resources to kinda back up some of it, you know there's not time, so so like for RBE 1001 for programming there's like a third of the lectures are programming and sensors and so you kinda do the math and there's. you know for somebody who has never programmed before having three hours or something of explanation is really not enough to get them going and then it goes forward you know in the 2000s well it's kind of the same thing we are very limited. So we did the Bluetooth lab I mean lecture which didn't make it into a lecture it spilled over into another lecture, and then it would have been nice if there was even more time than that. You know people could play the stuff and so on. But there's just there's a lot of stuff that we are covering so whether or not we are covering too much stuff or not. I don't know. It is a lot of work. Although I have a friend who was in the CS department at Stanford and I was talking to him one day. And telling him about how the group was complaining that there's too much work in robotics here. And he said oh you know, How much work are they doing? And I said you know Twenty, twenty five, you know maybe thirty hours a week. and he said for every CS courses at Stanford, the expectation is that students will spend thirty hours a week. Working on the course. And I said, well that's crazy and any said yeah if you want a Stanford CS degree, that's what you do. And um, and that was it, so I don't if all the classes are like that at Stanford but the CS courses certainly were. And so they work real hard, but you know they. get good jobs. So the results were good.

NG: Moving on to the final project what strengths and weaknesses do you see in current final project?

BM: So the set up maybe a little complex. You know making it all work. I mean it worked for awhile and then last term... I think last year or A-Term the first year that I've never seen a thing not work at all. You know. I mean, guess it was a little bit flaky. I mean you guys used it. I'm not sure how good it was working versus not working. But that was a little weird. The rest of it is pretty good I mean you know, I like it, Like I said I see like really creative solutions are doing that linkage to get the fuel rods. You know from vertical to horizontal vertical and horizontal to vertical and different heights and all that stuff. Surprisingly interesting solutions, often. and that's kind of what we like to see. You know, we like to think that the students are you know thinking for themselves. And come up with like ideas you didn't even think of.

NG: And what either what aspirations you have for the final product or what opportunities for improvement do you see in the final project?

BM: Well so besides, lets see, you know improvements, you know besides the equipment stuff and get everything you know running...Uh I don't know. It's uh, It's not bad I mean you know you learn about you learn about message protocols you know do all that Bluetooth stuff, you learn about, you know you're right. I think it's like the first time in RBE that you write a pretty substantial program maybe a final project in RBE 1001 but but this is this is a pretty substantial programming thing to be able to pull it off and you know and do it right so, so you know that's,

that's pretty good and if people. Uh you know. So I think that's good and that it's a really good outcome. because otherwise you don't write big programs until you get to software engineering or something. In the robotics sequence and having the opportunity to actually do real stuff is pretty good these you know they are getting up there in programming complexity.

NG: All right that's the last of our questions is there anything that you would like to let us know?

BM: I'm not sure if there's anything we have to talk about before. I mean we've been doing this for awhile.

NG: Especially yesterday.

JR: Anything that you want to be stated officially for the record in in the IQP report.

BM: Oh.. Uh.. I don't know. No no not really I think from my point of view the big thing is making sure there's adequate time to cover whatever is that we are covering. And that the labs and the lab materials and stuff really all work. I mean you know that it's not.. Burdensome you know for the students in a way that it shouldn't be. You know that you should be focusing your time on a hard part which is doing in the nuclear fuel stuff. Or looking for the candle, or whatever. You shouldn't be spending your time you know trying to find parts or you know trying to make stuff work that you're not supposed to be making work. You know, the stuff should come working. That's, you know, that's kinda disappointing that happens in across all the classes you know like the arms don't work or the field doesn't work or there is not enough parts or something you know for whatever reason. And I'd like to see us do better about that kind of stuff. Does that sound like..

NG Yeah that sounds perfect.

BM: Is that your ideas about, like I don't know what you are trying to work with this stuff but it's like last time I just heard all these. Especially last term I heard all this input I mean people couldn't find.. people were taking um. What were they doing? Motors or something. You know during the competition at the end of 1001 that people are taking like motors from one robot when they weren't playing to the other robot. You know so that they could play. Or something or some significant part which are peeling off a robot just while somebody was up there. You know as a loan. And when they were not up there they were giving it back to the other team so they could play. And it was like you know. Well come one. That's just. That's not right. And uh certainly it didn't start that way. And so that's pretty crazy.

NG: Alright thank you for your time.

BM: You're welcome.

Kevin Harrington - 1/23/2018

NG: Alright first off just so we like know for our records, What is your name?

KH: Kevin Harrington, I don't think the mic is going to be able to hear you

NG: You know it's it's been able to in the past we've done this before

KH: Sure.

NG: And are you okay with being interviewed recorded and transcribed and possibly included in our iqp report?.

KH: Yes, absolutely

NG: Are there any complaints or points of frustration that are frequently expressed during your office hours? And what are they?

KH: Im the person depends for complaints so that, that's a pretty broad question

NG: Yeah.

KH: I got a lot of requests for specific things that people would like to see in labs. I get a lot of complaints about things getting disappeared that we had a lot of and and just go poof and I have no idea where they went that that's definitely a complaint. With respect to the lab equipment there's just about everything in the one thousand and two thousand classes is ready for a refresh. They were slapped together when they were put together, and even sort of lived along on too small budget for a very long time. So things break that shouldn't break. Things are no longer available that used to be available we used to be able to buy parts now we can't buy certain things. And more recently I'm discovering the intercompatibility of those parts that we couldn't buy anymore and had to get new ones of don't seem to work with the old ones so power ratings on the H-Bridge and the motor weren't upgraded together so the driver can't drive the motor.

KH: Right now I'm just playing a lot of catch-up, its a year in and I'm still playing catch up still trying to figure out where everything comes from. Still trying to figure out how to create purchasing rules and inventory system to keep track of this. Very complex set of interdependent components and on top of that adding production to it, we didn't have prior. We had no production. Boy did I get complaints about that I just kept buying printers until they forced me to stop and now im buying more printers with another budget I'm just buying printers until people say we've got plenty of printing. Hasn't happened yet.

KH: Specifically with the labs some of the lab procedures are a bit old and out of date. Mainly the architecture is through the nineteen eighties nineties style architecture microcontroller for robots that's not the way robots are built. In the modern context you don't really start working with modern style robotics until you get to the current incarnation of three thousand one. Modern robots are distributed systems of multiple processors communicating together so we don't have a very modern architecture anyone who's computer science oriented will complain about that and then the more mechanically oriented folks look at our Vex system and say "oh my god this is not what you were thinking of when we want to design" so.

KH: There's too much of a toy like quality to a lot of our materials and not enough serious models of engineering even if they're not proper industrial engineering tools. They don't even model the architecture of industrial engineering systems. So I would say that sort of the most important complaint that needs to be addressed is the fact the architecture no longer models what it is our students are doing when they get into the real world.

NG: Are there any aspects of the course that have particularly poor student performance overall? And what are they?

KH: The 2000 labs have gotten disjointed, They don't flow together anymore, there was a time when it was a Unified story from one thousand one first lab to three thousand two last lab that you were walked from concept to concept each lab lead into the next lab all the labs in a class culminated in necessary technology that you needed to know for the final project, final project sort of an example of a canonical robot type that you would work with in the real world, those canonical robot types for each capstone lab. Could have been seen as a system that itself work together.

KH: That unified vision has gotten muddled over the years things have been added to the labs, things have been taken out of the labs, things have been added to class, things have been taken out of classes and the unification is gone so especially the two thousand labs become the dumping ground for "oh they need to know blank". And they make a lab on stepper motors. And they never do it again. And they promptly throw away the stepper motor, because fuck that shit, you know, who actually uses that garbage. You know, the line tracker for 1001 what I mean "let's take a analog sensor and reduce its resolution from twelve bit to one bit that'll make it better". You know these sorts of problems are not major problems taken in isolation but the culmination of all these over time has really muddled the waters in terms of what it is we're trying to teach and the process by which the lab's present those pedagogical objectives .

NG: This might be kind of related but how do you feel about the labs overall?

KH: If I could change things- well as I'm tasked with the process of updating labs. There comes with that and update the teaching objectives or in the very least a reevaluation of the labs against the teaching objectives. My plan is to... every five years there's an update to every single class, which means every year one class gets full attention to be updated. I'm not super excited about having to update three of them in one term. Moving into Foise that is quite upsetting because it does take a full time attention to update even one class especially a class that runs every term like 1001 that's there's no room to fix things so. I would-- I feel anxious about the update process.

KH: It's probably my biggest concern, but in terms of the objectives in the content of the lab I think that most of them are pretty good a few of them could be tossed and with a better architecture that my concerns would actually be mediated relative easily and the return to that arching objective, that full arch of pedagogical process that I think bringing that back and making them more visible would be basically the coolest set of labs we can imagine, I mean building robots that would be awesome to see that ahead of time and see how your skills are built from concept to concept to get from nothing, and you do assume kids will come in with nothing, all the way up to programming our distributed processing network of multi robot collaborative blahblahblah.

KH: I think we are missing classes also autonomous driving, legs, we don't have any leg teaching gate generation none of that  
MC: Great four thousand level courses?

KH: Yeah four thousand level courses I am super excited about the idea of four thousand level courses which Jing , the new director, was at the first programming was pushing Four thousand level classes such as driving explicitly autonomous driving, Ackerman steer and image processing, AI for navigation, AI for robotics, we don't have any AI for robotics classes. Just that alone would be useful. Reinforcement learning in boulder studio would be AWESOME, and would actually be really easy

KH: Anyway yeah so there are ideas for better labs, that classes. The the the driving force work, and with the updates to the budgeting process and the updates to the labs over time. I feel good about the future, I'm anxious about the present.

MC: So you said that you think that some of the labs could be tossed, do you have specific examples for that or is it just a general idea?

KH: I think as a robotics engineer new designs involving stepper motors is probably a very niche speciality. That is flat out unnecessary. I think the use of very low end sensors such as the flame sensor could be replaced with, uh, not necessarily tossed, but replaced with newer technology versions I think we should be teaching with the infrared camera from the Wiimote, not a single point flame sensor, that's absurd in this day and age we have better sensors, we should teach with them, you know, every VEX sensor that we have and any lab involved with them, toss. The VEX sensors are garbage in and you're only ever gonna get garbage out, so nothing from the VEX system has been proven to be worth the investment. This is a significant investment also. The mechanical labs where you bolt together little pieces of plastic that. Yeah that just the way that the things have design removed from them because production has never been part of the lab procedures I feel like a more useful four-bar lab would be design and implement and print functioning useful, emphasis on useful, four-bar. Or a multi-link or you know...

KH: On and on and on you can sort of replace these. Slap together some piece of shit and then do the math to predict how it should have behaved and then notice that it doesn't. Do the math to predict how it should behave, CAD model it, and demonstrate that it behaved that way and actually get the result that you expect as opposed to saying "well in the real world things don't work that well", it's like, "well, you know that they work better than they do with the VEX parts", you know? so there's there's a little bit of the the way we present materials in the the objectives because we don't require production and.

KH: Oftentimes have to remove any requirement for production problems but the lab and the homeworks all the way through. We've made sort of slapdash decisions on the mechanical side and there's no electrical there's you know no real electrical design all electrical design happens in CAD, like this is not, you know, you you would never use something that was hand soldered together or maybe you have and it probably broke or caught fire, because nobody does that anymore that's absurd you don't do any PCB design, there is no lab for PCB design, if you wanted to do an electrical lab in 1001.

KH: Don't botch something together on a breadboard actually designed a printed circuit board and get it made. I think that would be far far more useful than knowing how to digitize an analog signal. So it it is it is it a tweak of objectives to introduce modern production techniques throughout the curriculum and anywhere that it's a technology that's wholly obsolete like the stepper motor. Stepper motors are common. But not in new designs for engineered system.

KH: CNC machines don't use stepper motors anymore, they haven't since the eighties. There is a reason for that, You know, BLDCs and encoders are where it's at so, that kind of technology in fact maybe even just replace a stepper motors lab with a brushless DC lab you know do the power ratings on comparison between you know a brushed DC and a brushless or brushless AC you know for that matter so do that comparison I think that would be a more useful, useful set of tools, less about the the older technology. I would I would go through the labs with a fine tooth comb and look at any sensors, mechanisms, or circuits that are uncommon for a modern engineer to interface with. Then replace them with the common stuff that we don't teach.

KH: Don't do any PCB design. Boy, we should probably should have that concept in everyone's mind.

KH: We don't do modern motor technology, and yet they go off and do it anyway and maybe make mistakes and break stuff and hurt themselves, because they don't realize that that little tiny motor is as powerful as a motorcycle engine.

KH: People say, "Well, it's just so small!", No no no, BLDCs are crazy density so... you've got something like that, that can rip your finger off, and you don't even realize it, and you're sticking your fingers in it.

KH: There's a certain amount of engineering.. Pragmatics, the heuristics of design, that get lost if we're not getting practical experience of modern technology.

KH: Android would fit in that category as well, versus Arduino.

NG: To, kind of, switch topics for a bit here, what do you think that the labs look like from a student's perspective? Like a, sort of, day in the life of a student taking an RBE lab, and specifically 2001.

KH: Probably a bit bewildering.

KH: The lab kits are a bit old. Some of them are poorly maintained, which is more of my fault than anything.

KH: And there doesn't seem to be a lot of coherence as to why this lab followed that lab, this is more probably 2002 than 2001, but...

KH: The lab where they're meant to measure the velocity of the motor and they use a Vex encoder...? What? I mean c'mon. It just doesn't work, like, it just doesn't work correctly.

KH: It oscillates, it has friction spots, it has high spots, low spots, it wobbles all over the place, the signal is garbage, you can't get better than like a fifty percent off the baseline measurement because everything is wildly oscillating.

KH: Each cycle is what you're measuring, that alone is absurd, it probably seems absurd.

KH: And you don't end up learning good engineering principles, that it's worth taking the time to measure, what we want them to learn is that it's worth taking the time to engineer it, and then build it, because what you build will match your engineering model.

KH: That doesn't work if the hardware doesn't match the spec that we give them.

KH: If the hardware doesn't work, then their model is worthless, then they don't see any value in doing models, and we're producing hackers, not engineers. That would be the biggest, sort of, concern that I would have overall. It's the type of mindset that is encouraged. It's encouraged that user, "Oh well, I'll just ignore that it's off by 50%"

KH: And, and just, you know, average it.

KH: That's not engineering, that's hacking.

KH: So I think there is a slight disconnect between a rhetoric of engineering, measure the models first, design, validate second.

KH: We instead encourage them to engineer a design first, put it together, and then fudge all your numbers to make it look like your model for the report, or explain why this is no good so people just... getting used, as part of their lab procedure, to making an excuse about why it didn't work, well that's built right in, then why would anyone bother taking the extra time to make something work? The assumption is, it doesn't work, right? Dot dot dot.

KH: I think that the experience from a student's perspective is going to be encouraging them to not engineer in the labs and instead play games.

KH: Y'know.. Pointy haired boss.

KH: Send stuff to your pointy haired boss, that doesn't understand, just fudge numbers, making whatever they expected, give them a piece of paper that matches their expectations and engineering principles be damned. That I think is a confusing narrative.

KH: And it comes from, essentially, old hardware, it's weird. We're just past our prime on a couple of those systems, they can't be refreshed, except as a big batch. So now is the time to look at these problems, look at it for what they are, you know, we're not doing as good a job here as we could be doing so, that implies there's a better job to be done.

NG: Very good. On the flip side of that coin, what do you think that the normal lab looks like from an SA/TA perspective, what do you and like your supporting staff have to do to make it flow?

KH: Constantly finding the difference between a student making a mistake and bad piece of hardware is stressful. It would be a lot easier if a TA could say, "well, it's not the hardware, its you."

KH: Its very.. enjoyable. I would say, for the the staff, the 3001, to be able to say that now. Everything was tested, for the first time, we've actually managed to get that done ahead of a class, every piece of hardware is tested. Fortunately each arm can be tested as like a single unit test, and then everything for all seven labs, or six, five, or whatever it ends up being, is tested all in one shot, that's great, you know, and that makes this easier, but with the random components... "Is this op-amp not working?", Well, we don't have good unit tests for that.

KH: Now is it the microcontroller pin, or is it the amplifiers' input, or is it that wire or is the little piece of plastic on the arduino, or the metal inside is spread open? There's just like so many different points of failure, and over the years, every one of them has gone bad at some point, so it's really hard to just like, check it out. So I would say yeah you know their experience is wanting to be competent to explain what it is, that the student is doing wrong when they're getting bad data but then also having to couch their terms, with respect to saying, well you can't just blame the student necessarily in their mistake, because it could also be the hardware, but we don't have great ways of testing that.

KH: If we wanted to make their experience, the TAs and SAs, better, I would say for every piece of hardware that we deploy, should have a separate testing jig.

KH: A way to test this piece of hardware versus that piece of hardware, as a jig, as a unit, just like red light, green light, this is working, this is not. So we can, very clearly, see side by side, the difference between your code and my code.

KH: Whose fault is it here? Because if we can always say the hardware is fine, do your lab, and then, of course, the lab procedures have to be reasonable, then it's... You know it might seem harsh, as like, "no it's just your fault", well.. Yeah, but

then all the people for whom it wasn't their fault, we don't get those problems, so it becomes easier and more stable for the teaching staff to be able to say, "this is how it works".

KH: This very clearly works the way it's supposed to work.

KH: Yeah.

KH: If it's not working, you made a mistake. That would be something that the TAs/SAs would like to be able to say, but can't. It would make the experience, not only for the TAs and SAs better, but the student experience is going to be better because they're going to always get a reasonable, real answer to a question. "This isn't working, why?", it is like "well, you broke it", or you know, check, "nope, it's not broken, your circuit is wrong".

KH: Or, "hey, you know, your code didn't break it, this pin is bad."

KH: These sorts of things are not easy to do right now, they take a huge amount of time, just boil down hours of frustration on the students and hours of lost teaching time on the TAs or SAs to, "yeah, actually, this op-amp is just bad."

MC: So, would your solution to that be moving towards larger, more like, pre-created systems or just creating some sort of plug and place board, that you could just put it in?

KH: Well, I mean, both are necessary, there's a more unified controller framework, more commercial off-the-shelf and less in-house developed would be better. And the ability to have a unit test for everything so, you know, it's not either-or, its both of those things are necessary.

KH: You know, the thing that needs to be made, is the jigs, those are actually production things, zero insertion force sockets, and testing jigs, and a microcontroller to run a test, and give a result, you know, a way of reflecting to the tester that the test passed or failed, making sure those are robust.

KH: You know, some of this can happen in terms of one piece testing the other piece.

KH: You can test communications of a microcontroller and a phone just by plugging in the phone, saying are coms talking? Yes, no, cool. Check the I/O by the phone running a test for an I/O checker, which is a piece of electronics, which maybe feed back into the phone as a second set so you know, this is out, this is in, toggle toggle. Okay, now we see that this whole system's working.

KH: Unit testing hardware doesn't exist and it produces a lot of anxiety on the teaching staff's part, because they don't.. you know, whenever someone asks you a question, you want to know and be confident that you have the answer, if it's the hardware, they don't have that confidence. From the students perspective, it reduces bewilderment. "I don't know why this isn't working, this should be working."

KH: Well, yeah, it should be. You know, versus, "no, it shouldn't be, that is wrong for these reasons."

KH: And being able to say that if it's wrong, its wrong, and if it's right, it's right, but if it's right and you get the bad result because something's broken...That's where frustration comes from.

KH: And that's the piece that we want to try to eliminate, the student expectations should be met by the hardware.

KH: And whether that's a matter of managing expectations ahead of time, or making sure the hardware is bulletproof is a matter of debate. I would err more on the side of bulletproof, because, no matter how much you explain to someone, they're always going to come back with, "but I paid 60-blahblah", and it's like, "well, yeah, you do"

KH: You do, that's a fair point, so we're never gonna be able to just like, explain away hardware crap and deal with it. What we can do, is say, "this is, you know, how it should work, and this is the unit test to test the test.

KH: You know, and have something objective to lean against, rather than this, sort of, rolling chaos of hardware and mistakes.

MC: Real quickly, how likely you think it'd be to get the PCB fabrication for Foise? Do you think it's unlikely?

KH: Eighty to ninety percent likely.

MC: Is that something you're looking forward to doing, or?

KH: Yeah? You kidding me? Yeah, it will be two-sided board, unplated vias, laser, not milled, point four mil tracing space.

MC: Sounds like you already got the funding for it. Or, is that the plan?

KH: Yeah, place is all funded.

KH: We're just waiting for the APBP to go through but we already preallocated a quarter million for the production labs and nearly half of that is the PCB machine, the other half of that is a good laser cutter, a big, big powerful one, and a large print queue, as the infrastructure that's missing across campus.

KH: Pairing that with the hardware store model on the other side of the room, or other side of the building for interfacing with parts purchasing, keep those things that are awesome, but take six weeks to show up from BangGood and China and all over the place. Keeping those actually on hand for students so that they can be used in projects. Anything with a six week lead time is not gonna work in a seven week course.

KH: That sort of models... everything we're missing, the goal is to put it in Foise and not repeat stuff we have elsewhere. But yeah PCB fab is missing elsewhere, so that's very high up on that list.

MC: So you've already talked about this a lot but, besides the things you've already mentioned, what opportunities for improvement do you see in the labs?

KH: I think, besides the stuff I had mentioned, I think in the process of unifying.

KH: At a.

KH: Lack.

KH: Would be.

KH: This idea of looking at infrastructure as both infrastructure but also project. a really good example of what I'm talking about here is professor Polis' software engineering class. They are building a piece of software called WPI-suite, but then they use WPI-suite as project management to manage the projects developing modules for the software, so they are both using it and also producing it. I think our labs could have a similar texture that we could both be using our...

KH: Imagine my office, not as an office, but as a giant vending machine of printers and parts, building that as components in lab. So I think the first specific example to that would this re-imagining the 2001 final project from nuclear fuel rods to micro-warehousing.

KH: You know if the model was a wall full of cubbies full of stuff and you have to run around a little constrained space like a tiny little hallway but then its gotta go really tall sort of thing.

KH: You have constrained space, go get me part from B3.

KH: Navigate to the location, pick up the parts, pull them out to staging area where they can be counted or de-counted, as it were, so you know, drop your bin on a scale, throw six in, take four out, how many are left?

KH: Put it back, update the inventory with the current quantity. That sort of lab would be a really cool lab, it fits exactly with the pedagogical objectives of the class already.

KH: Mechanisms, manipulation, navigation in a structured environment, communication with a coordinating dispatcher, nodes within the system.

KH: It's exactly the same architecture. Pedagogically, it fits the model. Number one, it saves space in the lab.

KH: I can put it on the wall, I don't have to make a table. Cool.

KH: Secondary to that, possibly more interesting is, boy, I could use something like that, so over the years as people come up with their solutions for this little tiny toy system, we can take the good ideas and say okay, yeah we're deploying that.

KH: And if someone comes up with a better one? Deploy that.

KH: And use it as a way of prototyping for infrastructure improvements. because ultimately, you know, purpose of the job of a roboticist is to automate something that was a job, so let's take the parts of my job that are a waste of my \*\*\*\*\* time because we can have a robot doing this and give me more time to do design engineering work.

KH: You know, which serves the same need and becomes a self fulfilling prophecy if we do that.

KH: Yeah that would be a specific example of an improvement to just one lab that doesn't create a lot of destruction in terms of change, but has this long term vision of utility, that that utility is something that I love the students to think about the robots they create to be useful, because right now, really, name one robot that you build in undergraduate, that you would use again.

KH: Like, uhhhh? You know, without significant modification, or complete redesign, very few, there are very very few projects that that fits with.

KH: And they're very narrow, however, store stuff and retrieve it in a tight confined space. Boy, I mean, I can't think of any organization that doesn't need that so.

KH: The way of phrasing what it is we're doing, I think increases the long term viability of the lab and increasing automation in our robotics lab, its a robotics lab, why are there more robots?

KH: You know that being one half, but then the other half of the students value proposition perspective they can point more clearly to the utility of something they've created, this is useful for this reason, I oh yeah I built an inventory management system, duh, didn't you as an undergrad? The ability to come in and say I've done something useful, verses, "Yeah, I made a robot that picked up fake nuclear fuel rods", "Oh yeah, really?" "Well, no, not really, they're just plastic rods and it was a tiny tabletop demo and it was acrylic."

KH: "Actually I didn't build anything like what I described and I you know we we called it a model but it's not even really a model." The more you drill into these projects, the more you have to start, the student has to start, giving asterisks on why this is useful or valuable and you just have to tell this whole big long story about why it's worth it.

KH: And some people are willing to listen to them, some people are like, okay, so you don't know how to do .. Stuff.

KH: Yeah, to being able to tell stories of the labs as useful, I think, is very valuable long term for the students and short term for all of them, actually long term for the lab as well, it's a long term objective change that has short term costs, build the new thing, but we're getting budget to do that, and mandate to do it so, might as well do it while we have it and try to keep these long term visions in mind and not compromise while making the decision, so if you can have that long term vision, you can make decisions about the the short term tactics with that long term vision in mind verses well we made a bunch tactical decisions what long term vision did that end up pointing us towards, coming to that later is less good.

NG: So speaking on the current final project, what strengths and weaknesses in the way, like, the status quo for the final project right now?

KH: The two thousand one final project?

KH: The field is falling apart. It was falling apart when it was first made, has continued to fall apart since, it needs to be rebuilt. The Bluetooth protocol is...

KH: I mean, the data that goes over it isn't the worst, but it's pretty bad, the way nodes find each other and connect is horrendous.

KH: The use of Bluetooth is not optimal, the fact that the simulator doesn't model the field accurately is useless.

KH: Or not useless but it means that we're probably better off just stimulating and then having the field at all.

KH: It's a good idea, but no engineer was tasked with implementing, with the exception of ??? code and the code is great, yeah the code in the field controller is fantastic, it doesn't talk to a reasonable circuit, the mechanical system is falling apart, nothing works great, it and good code can't save bad circuits, so you know as like the rods cross out the back and destroy the cups, the sensors don't work, that they have lately, I mean, just, on and on, it's a frustrating experience, and because it's frustrating...

KH: You'll get one of two responses, hands up, it's not my problem, it's not gonna work anyway, I'm not going to try, or, well this doesn't work anyway, so I'm just gonna do my own thing and go above and beyond with my own thing, those are the cool projects, but because they're not well focused on solving a good problem worth solving. We get these great projects that solved a crappy problem, you know, so, the best solution to a useless problem is still a useless solution.

KH: I like having there being eye to an objective purpose to the final lab.

NG: You've touched on this a little bit already, but ideally, what results would you want to have students come away with, at the end of the course, after their experience in the final project?

KH: I'd like them to have a project that they are proud to talk about at in an interview.

KH: I mean strictly speaking that's what all of this comes down to, these projects are your portfolio.

KH: Course work is ABET accredited but still new enough that a lot of the big players are going to want to see something a bit more concrete, these projects provide that concrete answer. Right now we don't see a lot of that, you don't see final lab projects on a resume, you could, you know if they were cool enough, they should.

KH: But for example you know any five hundred design class, I can't remember the exact number but, almost always, you'd put that on your resume, its a design engineering class of four hundred five of four thousand five hundred cross list class and it's something that you are proud to have done.

KH: A lot of that stuff comes with interfaces with industry so there's like an industry objective that's applied to it.

KH: But I think in our case we can take a general case of an industrial need something that's specific enough to make a project about, but general enough that it's applicable of crossing the streets like ...stacked tracking.

KH: We can point to that very clearly, this is an infrastructure that makes sense as a useful project, so boy you want to talk about that, you want talk about how you understood these practical problems, how you actually succeeded, again, getting back the hardware being successful, if the hardware is successful, then you talk about it. If the hardware doesn't succeed and the expectation is it doesn't succeed, you just do enough to get your grade, you know there's some minmax here that everyone that knows is well you know I can get it working, or I can take a B and write a paper, and call it quits, we don't want that attitude, we want the expectation that it works.

KH: Just just expected, you must expect that, and everyone should be able to expect it, but everyone makes excuses here and there you don't see that coming out, so I want that expectation of completion, and I want something that is valuable enough for the students to want to brag about having done it.

KH: Yeah imagine Keon's Small Cat was a four thousand level class, you designed, printed, and got walking, one of those things and had one, literally had it.

KH: I'd bring that to any interview I go to, that would, \*\*\*\* yeah, ya know? Like...

KH: Or bring up YouTube, so you know so, here's the big dog, here's mine, you know, it's a little bit cheaper, but we did also do it in seven weeks, and I learned from scratch, so like you can tell stories.

KH: And this gets back to you know, the purpose of any of these labs is, if you have good hardware and have worthwhile laboratory objectives and reasonable laboratory series to get you to that objective, then it becomes something that is tangibly valuable in an interview.

KH: About explicitly what you did in this project team how your key solve these problems and didn't just work on a problem solved it says that's a big distinction you don't see a lot of at the undergraduate level undergraduates work on problems you know grad students solve problems, phds create problems.

KH: If you can get to that level where you're interacting with the the interviewer like someone who has a degree above what can have, that's valuable, that is valid, you know and that's a differentiating factor in the labor market.

NG: Alright, that's the last of our questions, is there anything else that you would like, that we did not ask, that you would like to be known?

KH: It is very important for us to move to more sophisticated architectures, the recommendation for android as an example case or android-teensy module systems is one that I would be very interested in seeing strong arguments from the student groups, pushing as well as me pulling from the top side.



KH: We are not making the kind of robots that you would ever see in the real world, microcontrollers are not it.

KH: Knowing how to deal with distributed processing is very very valuable and, to be perfectly honest, we're probably gonna push that more in 2002 than 2001 because it's more of a sensor class, but making sure that that narrative is part of the story, also something that that you can talk about for lab integration.

KH: You know what'd be a really great thing to put at the end of the robot for two thousand one? A three thousand one arm.

KH: Doing pick and place loading and unloading the little boxes that the two thousand one robots are retrieving.

KH: Now.

KH: Even the.

KH: A lot of cool software that, actually that gets really interesting you know integrating having like a three thousand three that's actually a lab practical lab integration of two thousand one three thousand one and a manipulators class or an ERP, you're actually doing project development now, you know, there's a lot of really interesting recommendations that could spawn off of this as ok if we look at these labs as building towards a series you can tell stories about how this lab fits into the larger narrative with other classes how these other labs make more sense, if you could imagine to the two thousand one cubby wall as a hallway within a factory and the three thousand two robots are navigating around the factory, so maybe there's a robot arm that three thousand one arm, to pull the components out of the two thousand one cubbies will load them on to a three thousand one robot, have them drive over to another different two thousand one cubby system and have them load it over there, like the full system integration, something that nobody has really thought of, and we don't think of our labs anymore in that context, and anything re-imagining that architecture as a model of production from the labs' perspective.

KH: Helps tell the story in a clear and coherent way, for all the students, so that I would make sure that there's some understanding of yeah this is this course and this is this lab, but this is how it fits in the in the bigger picture, keep the bigger picture in mind as you as you may call the decision on because ultimately these students are going to watch the next class and the next one and the next one and the students wind up there just even more bewildered than before.

NG: Alright, thank you very much.

## Appendix G: Student Assistant Interviews

### SA Interview #1 - 1/18/2018

NG: All right so just for the record, what is your name?

SA: My name is REDACTED.

NG: All right and are you okay with this interview being recorded, transcribed, and included or quoted in our IQP report?

SA: I am fine that.

NG: How long have you been an SA for 2001?

SA: I have been an SA for a full year now, I am a Junior currently and I started being an SA sophomore year C term.

NG: And how do you feel about the course overall?

SA: I think that overall the combination of the material and the helping staff makes it a very good course and fun course. I enjoyed my time in 2001. I have not seen too much struggling going on, I've never seen anything exponential like major change. Happen in 2001. As it goes the wraps some people still struggling to project at the end and I don't think it's the... It could be worse. I think that there definitely harder classes on.

NG: Alright, how do you feel about the labs overall?

SA: I think, personally, that the labs contain a lot of different material. I would like the labs to be more cohesive so that they work more towards the final project because the way I see the labs is: here's some information, you can do one thing with, here some more you can do another thing with. It's like to just briefly teaching kids Mathcad, its teaching them how to do PID, teaching them how to LabView, and then that stuff just really isn't used much later on, so I think that if like the three thousands. I know this is an introduction class what they're still are better ways to integrate. All the information together. I think that would make the labs just that much easier.

NG: What do you think the labs look like from a student's perspective.?

SA: I think... At first they appear kind of daunting because, My lab is only eight parts but I am here I am spending five hours working on it. Or, there's just a lot of new material going on, but I think that... has... obviously we're looking back on it, I think that the labs are a lot easier. And that... I think, it's mostly the software that we're using that's kind of confusing to the students. Not as much as necessary like the labs themselves, as labs have been worked and reworked, trying to optimize information and time spent... so I don't think they're that bad overall, but from a student's perspective they can still be daunting.

NG: What does the lab look like from your perspective?

SA: From my perspective it seems like the labs have the proper amount of information and time requirement. I don't think it's excessive at this moment. But... I think that, again, some of the software is not fully necessary to make them learn these things

and every single one of these things. But... Otherwise, kind of compressing it together would make it more efficient, but I still approve of the labs overall.

NG: Have you noticed any aspects of the course that have particularly poor student performance overall? What are they, and what do you think the cause of this is?

SA: I don't think any specific things like the homework or the labs are all that, I don't think any of those specifically. People struggle on the final projects, that just because they're the final projects and that's like the hardest part of the class so it's gonna be like that and it's a bit... I think that sometimes the final exam takes up a lot of time, or, when I took it, there were people who require extra time to finish it. So I think that overall the student's perspective is that some things are a bit too involved but I think that the homeworks are a good, kind of, beginner introduction to the topics, just to make sure you know, I feel like the homeworks are very easy... I don't think the labs are too bad, and the final project... although being time consuming, that's expected from an RBE final project.

NG: What are some common pitfalls that you've seen students stumbling on during labs?

SA: I feel like a lot of people just have some... one random issue, like they put a wire in here wrong, and they set this up wrong. Like I saw... I've been seeing a couple things were just on the function wave generator, you don't turn one of the dials enough, so it doesn't have the right response, and then people struggle like twenty minutes on that, but that's... so just, like, very small things. I think that students are grasping the major topics, but, having to then... take this information, put into just the... small... like anything can go wrong in a lab, kinda. So I think... that's... where most of the issues would lie. But I feel like students, overall, understand the material.

MC: Are there any common issues that you've encountered as a SA for the course?

SA: As an SA... I don't think I've... Stressed too much. I feel like I have plenty of stuff that I could have going on, I have the necessary amount of office hours and all that I that I think I could even do more as an SA if I needed to for the 2001 so I like being able to keep the costs optimize and efficient.

MC: Next question do you think the students would be capable of completing the labs on time without help from the SAS?

SA: I Do not. I think the students. Without TA/SA help I do not think that the students would be able to finish a lab with a passing grade.

MC: Can you explain why.

SA: I feel that. Some of the specifics in the software that just completely brand new to students like Mathcad or Labview or any of that style stuff I feel like it's students were just asked to kind of learn this I don't think that a week's worth of time considering the amount of information that we require them to complete in the time is enough. But that's why we have four SAs into TAs all going for around almost ten hours ten office hours a week. To make sure that students can be able to understand everything going on and then there's that combined with the lectures and homework and the final project altogether so I think that the SAs and TAs are integral in the labs.

MC: How do you feel about the final project?

SA: I think that the final project overall isn't that bad. It requires a lot of time when I was in the taking a class at a pull one all nighter which is pretty standard for army but still not great considering. College in general, but it happens. I think that if students were a bit more prepared and I think they could be a bit more prepared during the class itself. Just the way the curriculum is set up, I don't think is optimizing or to helping with the final projects mostly because like a lot are directly related. I think there's some things that are relevant like teaching Mathcad equations to help solve or free body diagrams and analysis of their robots but otherwise I think the final project is doable. I've never seen like.... Obviously it's hard to find a team that completes every single aspect on time without any all nighters requires time and effort but I think that just the way RBE is.

MC: To go off track a little bit since you've spoken about this multiple times. You said that you think that's a lot to be optimized more and that there are things that are in the labs that perhaps shouldn't be on other than what you just said do you have any other examples?

SA: Some of the software like Algodoo and Norton just isn't very good at this point in time it's sure you can use it to model second lab aspects however I don't. Think those. That's important enough for the final project where most students would prefer to use something else. Some other kind of software. So I think there's too many different sets of software. I could list some other time maybe but just having to randomly okay I just finish this step where I'm testing the oscilloscope now I have to go and plug in my arduino to Labview I just. Look at the RC filters. I just think that. There's too much different systems that were having people manage in 2001 but it's not something I remember. Spending one fourth of a lab working in some random software is not something that's really memorable coming out of 2001.

MC: Once a solution that we've considered is instead of having Norton, algodoo, Mathcad another thing that we need to focus on later in the 3001 3002 series is.

NG: Students are kind of forced Matlab and if we started incorporating that earlier and perhaps use it for some of the things like MathCAD and solving equations and using that kind that way to perhaps provide more of an introduction to think they'll be better than using MathCAD .

SA: I think Matlab is a very efficient software and I think based on what I've seen that can do a lot of different things especially the 3000 series and from what I've talked to Kevin and to the professors to other TA's and SA's like they also Approve of Matlab. And I think that 3001 shouldn't be my first robotics experience with Matlab. I feel like that integrating even a year early as 2001 just some brief technical quick things to learn just as an introduction would be very helpful for the class. I think that trying to sync up a software is between classes as well would be helpful because, Although it just feels like the way it's set up each classes like okay you're gonna have to learn this chunk of information then this chunk then this chunk and although some of the materials carryover I feel like it was integrated even better would help RBE as a major.

MC: What do you think about the PDR and CDR process?

SA: I think if it is clarified what's going on then it's helpful. Sometimes in the past it seems as though students were not prepared for is because they're not entirely sure what they're presenting because this is their more or less first time doing the CDR and the PDR but I think that if given like since this is our first time and we tell them specifically okay this is kind of the kind of information we're looking for this kind of map we want to see the information you want to give us I think that those specific guidelines would help out with it. And if given that I think it's fine but you're told just give us just a presentation the robot I think most students that would see as on my don't really know what's going on what they want so they're not entirely sure how to approach that.

MC: What do you think the purpose of the PDRs/CDRs are in your opinion?

SA: I think the purpose of the PDR and CDR just make sure the students are starting on the final project, because... A lot of hard... like, the classic joke is you have seven weeks to do a project, why haven't you been doing it? Why that's so hard but it's like well we have so much other stuff going on and that sometimes people think with the labs at the homeworks with class itself that they just kind of forget about the final project so it's like three weeks left, now I need to start the final project. Because I remember 1001 you can only set up on a project the last three weeks. Because you didn't other parts of going to get. So I think that the purpose of the PDR and CDR is to make sure that teams are putting in time thinking about their final project before it becomes too late.

NG: Follow question do you think it's a fills that purpose?

SA: I think it's close to fulfilling it. I think that a little bit more can be looked into it and make it more efficient. I don't think it fully. Establish a just because I think a lot of teams don't take it seriously I think if everyone took it seriously and put in some of the upper level thresholds that I've seen work put in. I've seen fully CADed robots and exact field models like the robot will be here on the field doing this exactly and I think that can really help out the team but also it's a lot of time. So I think that. From right now it's. It could be optimized again.

MC: How do you think students feel about the final product?

SA: I think students get stressed out by it obviously. Like going through. 'What major are you?' 'I'm an RBE major.' 'Oh, I'm so sorry' is a common saying on campus. Because you hear about all nighters and late nights working on campus. And that is because of the final projects. Students are kinda afraid of it. Students shouldn't be concerned about putting a lot of time into the final project more than a typical class because RBE has five specific classes you need to take RBE 1001 through 3002. And when you compare those final projects to all the classes you have to take if you are an ECE major. If you are and ECE major you have to take twelve classes. Well you probably have projects in that time as well. Because RBE has that kind of less class approach I think students should be less concerned about the final projects. And that if they do put in enough time and that they have a group. I have TA's. I have SA's. I have a professor I can go to with questions. Then they don't need to be afraid anymore.

MC: In your experience, do students usually finish the final project?

SA: Depends on how you define finish. Well, the grading rubric is a little strange, but I think that most students pass the final project, a majority of students would, I believe, based on just the final project, a majority of students would grade over a 70. I did not finish my final project on time. I did not get everything done on time I wanted with it. But I think there are a lot of different reasons for that, but I feel like on average more than 50 percent of the students would get at least a 70 on that final project.

MC: Is that before the curve?

SA: It's not exactly curved but it's graded on more than a hundred points so you can. Ok so I would really really like this final project grading rubric to be fixed because it makes no sense. It's like this is 25, 20, 25 bring it up to like 240 points. And it's like what? That's different though. That's just something I have issues with. But I feel that visually speaking it's probably up to 140 points. Where as a 100 is actually a 100. And I think most students would get enough.

MC: Is there anything else that you would like to say. Questions, comments?

SA: I think that in 2001 that everything was mostly covered. I think that a bit more cohesion between the course and the other classes would be nice. I think that that pretty much everything. I really like the class. I have a fun time with it. My favorite part is teaching the help sessions. I just really enjoy that.

MC: I have another question, out of curiosity. If there was one area that you thought we should focus on, which would you say?

SA: I think that it's not necessarily that it need the most but I think that comparatively its the labs. I think that the homework. This is my opinion based on who I am now being an SA. but I think the homeworks could be harder. I don't think they are very complicated homeworks. I think the final project is where it should be but the labs could have more cohesion.  
MC: Ok. Thank you.

## SA Interview #2 - 1/19/2018

NG: All right could you state your name just for the records?

SA: REDACTED

NG: And are you okay with this interview being recorded transcribed and possibly included in our IQP report?

SA: Yes.

NG: How long have you been an SA for RBE 2001?

SA: Like two weeks at this point.

NG: How do you feel about the course overall?

SA: I think it's a good course that has a lot of material but that being said that it has like so much material it's almost hard to grasp it sometimes. It takes a lot to balance that with whatever other classes you're taking at the time.

NG: How do you feel about the labs overall?

SA: Um, overall, I think they're structured well, I think. Probably the biggest improvement could be, somehow, tying them more closely into the final project such that the work you're doing with them can contribute larger final projects is not like so segmented throughout the whole time.

NG: What do you think that a lab looks like from the students' perspective?

SA: I think the the labs seem... Some of them seem fairly... I'm not exactly sure what to make of this, um, I think the biggest issue with the student side of the lab is struggling with the equipment not working or the parks being not there or broken or just like the lab benches or computers or something or having some weird error some bug thing says that you're fighting with. The equipment more than actually, just, working on the lab itself, such that having to struggle through that makes it a lot harder than it necessarily has to be.

NG: What does the lab look like from an SA/TA perspective?

SA: Seems a little hard to tell having just jumped into that but, I think it's... I don't know it's a little... It's different saying it from having to... I don't know exactly this one... It's definitely a different... It's weird going through multiple of the sections and seeing how the kind of issues arise in your progress and you address them from like one section to another as you start figuring out more things. I think they're could probably definitely could be a better job of documenting those things that happened in trying to, actually, like, record them since the next term happens, you don't have to go through the whole process of discovery again

SA: And figuring out what the common bugs and the slight miss-types are, just things that need to be clarified, because as you go in through the next lab section, in your intro spiel thing you start talking more about the issues that are encountered by teams before but I think it could probably be documented better such that that starts out from the first lab section each time as opposed to having to kinda re-discover things.

NG: Are there any of these things that you can think of right now that you can remember specifically?

NG: That like you figured it out by like the third lab section, but you really wish that you had known it by like the first one.

SA: So one of them that I remember from when I was a student and that was still the same was the first lab, the relay part.

SA: There was a 1K resistor that goes to the transistor that you use for the first part and that switches over to the relay part for the second thing and the 1K resistor actually on some of the people's relays doesn't actually let it trigger because there's not enough power going through so you have to switch it like a hundred ohm or something for it to actually be able to trigger the relay. That wasn't something... That was kind of switched undocumented, and I remember that.

SA: Also this past lab we had an issue with the LabView portion of it, just because, we just I think... This year they switched up the computers, so when I took it, there were only the linux ones, so we didn't have LabView, so we used some other arduino thing, but we wanted to have, I think it was professor Bertozzi, he wanted to have the LabView for this one, so we got that installed but it was kind of...

SA: It happened only a little bit before the lab so we are only like fully testing it in the real lab section where we found that one of the libraries wasn't installed so we had to work through that in the first lab section when I wrote up something on how to do that and it was like fixed for the second one but just. That was one of the other things that going forward...

NG: Are there any common issues with the course that you've encountered with the courses as an SA?

SA: I think a lot of the electrical portions... students kind of don't have a super great grasp on using the actual components, whether it be the oscilloscopes, or, there's also a bunch of issues for the function generators and see people have a decent amount of issues with because they're the kind of old and not very intuitive with all the knobs for the amplitude and offset and all those things and some you have to pull them out to twist them and other things.

SA: And then some of the other things the more complicated things with like triggers on the oscilloscopes and actually measuring things properly.

SA: In addition to just some other silly things that students do, not realizing that all of the grounds have to be, common, and then they just have like some are over here and sometimes over here just kind of them not having great grasp over electronics and like some of these are some of the bread boards have like a split power ground rail so if you just plug things in and just assume it's all connected it won't actually worked because they're two different sides, which is kind of little things that students miss commonly because they're not super intuitive.

NG: Do you think that students would be capable of completing the labs on time without help from the SAs and TAs and why?

SA: Without any help, just purely on their own?

NG: Yes

SA: I think that certain groups will be able to, I think the ones that have...

SA: That either have more experience in robotics through other portions and have more experience with these tools and how to do these things would be able to. it would definitely be harder as there are some....

SA: Just small pit falls or just having

SA: Like debugging your circuit after you've been staring at it for awhile I think that if they.. if they almost used like other teams as SAs and they like talking between themselves just to have another eye look at things and they've been staring at it for too long and don't know how to work it and they'd be able to figure it out but I think it it's hard to do it would be very hard to do and just within one team if you didn't have any external help because you just kind of miss little things that are probably obvious be just overlooked it somehow.

NG: Do you find yourself working more hours as an SA/TA then you're allocated in the RBE program, to ensure that students taking the course can succeed?

SA: That's kind of hard to tell currently, I think so far, yes, mostly just because there's the three lab sections this time, and there's four of us SAs, so its between all of those lab sections and the kind of outside office hours and it just kind of. The office hours just kind of run slightly later or, just because I'm here and don't leave right when they're done a lot of those just kind of my choice of I'm just here doing work anyways so just random questions or things I'm just kind of okay with that.

SA: I did like settle my office hours such that a hard thing to leave at the end and I probably would be at the normal time limit but mostly the three lab thing makes it difficult this term.

JR: So that's a larger number of lab sections then there usually are?

SA: It's normally only two sections from what I'm aware of I think because it's on a thursday they have three, because trying to fit in people's schedules because normal class day...I'm not exactly sure about that, and I think the thing of one of the classes has to be on Thursday, because there's just not enough time in the day to have all three classes have labs on Wednesday so... Hopefully that's better next year, because they're having them split up. But who knows?

JR: How do you feel about the final project?

SA: I think that you definitely learn a lot out of it, and you get a lot of skills through it, and going through the process of having a PDR/CDR, and then the final presentation, in addition to your demo, is very helpful. Like I was saying, I think it could be tied more into the labs... better somehow? I'm not exactly- there's the fine line of drawing them, it's hard to integrate it perfectly into the actual laboratory exercises because those kind of... goals of each of them. The challenge is... for this class, which is mostly centered around mechanism design and like fourbar analysis and all that kind of thing the seems a little strange that the actual... thing that you have to pick up, weighs basically nothing so like all of the calculations for actual motor power and all sorts of things like that are kinda they're not actually stretching it all there because it just weighs nothing so you can pick it up with the smallest servo you can find, so and it turns into a, at least in my experience, mostly a computer science challenge, because, mechanically you can make something very simple that is able to complete it, just, coding it is the hard part, so if it was somehow... I'm not exactly sure, but somehow redesigned such that it was a...

SA: You had to reach somewhere higher from a small starting configuration and lift something heavier, or something that would require more in-depth mechanical analysis and actual more robust mechanical design I think would be more in line with the rest of this course.

JR: How do you feel about the PDR/CDR process?

SA: I think, as a whole, it's good and it provides you good feedback and it gets you thinking about that forces you to think about it early and Professor Bertozzi does a good job of setting milestones and expectations for what you should have at them, because otherwise people would procrastinate and leave it for longer so it forces you to get started earlier and it gives you feedback throughout the term of, oh you're thinking about this wrong or you're doing something that's pretty... That is kind of outlandish and not going to work, or like, oh yeah, you're on the right track, good job, kind of thing. I think that it's... I like that. It's not a huge portion of your grade, but it's just kind of a reinforcement thing you have to do and that keeps you on track the whole time.

SA: The PDR pops up fairly quickly after being in the class. It can almost be a shock of having to start something so early but that's just kind of the reality of the term and the project and what you have to do. And then that kind of ties back to if you

somehow get the labs to work on some small like one part of the lab is some portion of your final project throughout the whole thing as opposed to just the only thing about the final project in the labs are these design reviews.

JR: Are you aware of any teams making significant changes to their final project design as result of the PDR or CDR?

SA: So my team actually did this, when I was a student, I've no idea about..

SA: This term, because it hasn't happened yet, but we ended up changing our design around, because we had kind of a crazy big outlandish design that when they actually set up the field on the day of the PDR, the CAD model and the actual field were like different, in a not insignificant way, such that our like crazy four-bar thing that reached out to either side was less practical, just because the slightly wider distance and also the people there were doing our PDR pointed out a couple of the major weak points of the designs and a couple places that we may not have thought about as closely about these little features that are going to break or not be as robust as we thought, so that I definitely thought it was useful and we ended up changing a decent amount because of it.

JR: Just to clarify, when we asked you about the final project earlier that was from your perspective as a student because you haven't encountered it as an SA yet?

SA: Okay yeah, that's... yeah.

JR: In your experience as a student, do students usually finish the final project on time?

SA: In my class... Not really, a lot of them were using the time after the actual demo to be able to submit the video. I think only like... four teams? I'm not... that's not the exact number, but somewhere around there, actually fully completed the challenge for the time of the demo.

SA: And because he gives you till... Saturday or whatever it is after the kind of the last day of the term, to submit everything. A lot of students are definitely still working on it. They're mostly mechanically done but they're trying to fine tune their programming to get it to actually complete the challenge correctly and also, a lot of students, I think, found, that the final paper, in addition to the final project, was kind of put off.

SA: It's the .. Partially, at least, put off until the actual robot was done, to turn to focus on both at the same time in addition to whatever other finals you have, so it's just kind of a lot of things that are all due at the same time. Having the robot, the paper, and an actual final exam, just for this class, in addition to the finals for whatever other classes you're taking, such that its kind of a lot to balance and ... might degrade the quality of one or multiple of those depending how you prioritize it.

JR: Is there anything that you feel that you that we did not ask that you would like to know?

SA: I don't think so. I think your questions cover most of the concerns and kind of major pitfalls that I saw of the courses, mostly as I was a student, and still kind of see now.

NG: Thank you very much for your time.

### SA Interview #3 - 1/19/2018

NG: All right just for our records to keep them separate from each other, what's your name?

SA: REDACTED

NG: And are you okay with this interview being recorded, transcribed, and possibly included in our IQP report?

SA: Yup.

NG: How long have you been an SA for RBE 2001?

SA: For 2001 this will be my third time.

NG: And how do you feel about the course overall?

SA: I think it's good.

SA: It's changed since I first started teaching it, or assisting with it.

SA: And like all courses, it grows with the students and the technology

NG: How do you feel about the labs overall?

SA: They're showing their age.

SA: Yeah the labs for 2001 are somewhat disjointed, in some part because there's no... no one topic for the course.

SA: And so each lab needs to cover a variety of different things and it can be hard to have some continuity because a lot of topics are so disjointed and you need to have the background of some future labs, which means on the early labs may not be cohesive.

NG: How do you think the lab looks like from the student perspective? What's the student experience in your eyes?

SA: The lab or the lab? Like the lab as a place or the labs..

NG: regular lab like section or day.

SA: I don't know, it's been a long time since I've been in the 2000 labs.

Jacob: As an SA...

SA: As an SA?

Jacob: As an SA, yeah, what you think the student perspective is like?

NG: What was your impression about how they feel about things?

SA: I think there's...

SA: It seems like either students have a really good experience or they're frustrated by one or more parts of it.

SA: If they're frustrated it's usually because we don't have a particular piece of hardware.

SA: Like this week we didn't have the proper shaft couplers to [the motors we get in the kit to] the vex encoders, for example.

SA: And I think there's been some confusion about whether the lab kits are required... And that's something that has changed since I took the course three years ago and at that point they were, to some extent, pretty optional.

SA: Because we got enough parts from the lab to do the final project, to do the labs, and now we're moving toward [that] you need those larger motors in the bookstore kits to be able to do the final project because we're not providing motors.

SA: They're better motors than anything we ever provided, but the students that don't have those get very frustrated by that.

NG: What do you think the labs look like from an SA/TA perspective? So, it's the reverse [of the previous question].

SA: I think the first time you teach it as an SA, it's kind of all over the place.

SA: Because, you know, it's a different experience than when you took the course.

SA: Having done it a couple times, it goes a lot smoother.

SA: You realize what some of the common problems that students have in each particular lab... it makes it easier to debug common issues.

NG: Have you noticed any aspects of the course that have particularly poor student performance overall? And what do you think the cause of this may be?

SA: I would say the last couple of terms, I'm kind of disappointed by the quality of a lot of projects.

SA: They've got a lot of teams that have come and said, "we don't really have anything to show you..." or we have a couple portions of it that don't work together and then when they demonstrate those, they don't work.

SA: That makes for a pretty long day for us, as were watching twenty teams... sometimes show almost nothing and you also have a whole bunch teams that do really, really well and just put the robot down, it goes, does everything, and they're done in five minutes.

SA: And in fact that's pretty consistent... that there's a wide spread.

SA: It would be nice if everybody was on the higher end... when you've had success it means that you've learned a lot of topics in the course and you're able to apply them...and when you don't have anything to demonstrate, one, it's frustrating and, two, maybe they haven't picked up as much of the course content as they should have.

NG: Kind of branching off of that, over the years that you've been an SA, do you think that that wide spread has been getting wider? Or that it's pretty consistent.. or?

SA: It's hard to gauge, because it varies within the term, or between the two terms of the same year, but the labs don't necessarily change a whole lot... I don't know, without any numbers it's hard for me to tell.

NG: During lab sections what are some common pitfalls that you see and watch students like mess up this one thing like every time?

SA: People...the first lab that they have to do something with an arduino and a circuit on a breadboard

SA: Almost every time at least one or more groups forgets to put a common ground between the two [sides of the breadboard].

SA: And people often struggle setting up using the oscilloscope for the first time and setting up the function generator and in their defence, the function generators we have are terrible, and they are really hard to set up and they can be really confusing but people a lot of trouble using those and using the scopes for the first time.

NG: Are there any common issues that you've encountered as an SA for the course... Things that weren't quite good for you?

SA: That might be more of a question for the TAs because, as I say, our job is mostly to help the students and so our experience can vary a lot by the students in the course. You know it's not like we're doing grading or anything like that.

SA: If a different professor teaches, it might be different but...

NG: Do you think students would be capable of completing labs on time without help from the SAs and TAs?

SA: No, probably not.

NG: And have you found it necessary to provide any additional informational materials to aid the students in completion of the labs that you had to come up with you're on your own. And maybe could be worked in the course little bit better.

SA: I think we've done that some for the review sessions

SA: It can be easier to look into outside resources than to look through the lecture notes and find the ten side long derivation that you only need the final equation for and that's it really.

NG: Do you find that you spend more SA/TA hours than were allocated to you?

SA: At the end of the term yeah.

SA: At the end of the term were scheduled for ten hours but we might put in fifteen.

SA: There can be a gap at the end of the term. At the beginning of the term when people are struggling less with labs and they haven't necessarily started their final projects yet and aren't trying to balance that. People don't necessarily come to office hours and so there's less incentive to hold extra office hours at the beginning of the term than at the end.

NG: How do you feel about the final project?

SA: It's an interesting one. The design challenge of it... The last couple years it seems like people have been moving toward a single design almost everybody does a slider-crank system.... and that's not very interesting. It's...too easy. There's very little analysis to get it to work.

SA: Just to get it to work requires almost no effort, so as far as an actuation mechanical challenge, it's not a hard one. The thing that people struggle the most with on the final project is the bluetooth. Far and away, they struggle the most with the bluetooth.

SA: And it's not that it's particularly hard to do especially with the changes that have been made to the libraries the last couple years, they just don't start it early enough to work through the.. "Hey we actually need to do this bluetooth stuff"

SA: And once once they do it, it only takes maybe at most ten hours to do, but when you started twelve hours from the project deadline, that doesn't go very well usually.

NG: How do you feel about the PDR/CDR process?

SA: I think they're good... It's good for us as the teaching staff to gauge where all the teams are. You don't necessarily have office hours when the teams are on labs so you get another perspective on the status of teams

SA: And it's also good to steer some teams at least away from particularly challenging design decisions. We're not there to tell them not to do something, but to give them some design input from something seeing how the teams have struggled... An awful lot of teams avoid the pitfalls at the end of the term

NG: How do you think the students feel about the final project?

NG: When they come and talk to you, what sort of complaints might they have?

SA: So at least based on last term, a lot of complaints about the field, as the field was literally falling apart and the Android app was not a great replacement for it, and so that was frustrating for everybody.

SA: I know people get frustrated by the bluetooth because they don't start early enough. They don't understand what they have to do to make it work.

SA: Particularly people without a strong CS background who don't understand encapsulation and objects and such really struggled with the bluetooth, even though it's not a particularly difficult thing to do, if you have that background, it makes a lot of sense, if you don't, it's a mess of words.

SA: I think people's experience with it changed a lot based on their design decisions. If they design a poor robot chassis that doesn't navigate the field well, they're going to struggle a lot and be very frustrated by it. Making a good robot drive base and build your mechanism well, then it's a pretty easy project.

NG: And you've already talked about this a little bit but if you could just elaborate on like what the kind of like the final days look like and what happens to students that do not finish the final product on time?

SA: So if teams don't finish the final project on time there's usually a couple days allowed after the term to submit videos for partial credit.

SA: Up to the last few days there are people in the lab pretty much all the time, until the wee hours in the morning.

SA: Sometimes people are trying to tune it and get the last ten percent out of it, and some people are building their robot in the last week and they're the people who are staying late after the terms over, to get partial credit. Because if the robot doesn't move, it's really hard to get partial credit.

NG: That's it. Is there anything else that you would like us to know that you don't think we covered, that you think should be known?

SA: I don't think so

NG: Alright well thank you very much for your time.

SA: Yeah, no problem.

## SA Interview #4 - 1/29/2018

NG: Okay so just for records what is your name?

SA: REDACTED

NG: And are you okay with this interview being recorded transcribed and possibly included or quoted in our IQP report.

SA: Yes provided my name is kept anonymous.

NG: How long have you been an SA for RBE 2001?

SA: REDACTED

NG: And how do you feel about the course overall?

SA: Generally I feel that the course is too dense with content and requires too much of students. It is not cohesively structured such that you develop off of existing knowledge. RBE 1001 built toward a cohesively designed final project. So I guess my evaluation would be pretty poor.

NG: And how do you feel about the labs themselves overall?



SA: I believe that the labs individually have some educational value. I believe are they primarily teach electronics hardware and hardware design. You develop a lot of practical skills doing them but they're not cohesively structured such that one builds off the other. They do not, I believe match the titles of the courses in a rigorous way. I believe the titles respectively are Linkage design and sensing. Which I don't believe really suit the low level interfacing with sensors de-noising of sensors. Any electronics programming that going to the first four labs. The final projects although there in the works of being redesigned I don't really think are the greatest application of the skills learned in the course. I think that the challenges if redesigned could potentially be. Better used to practice the skills built on in lectures and in the first labs.

NG: All right, and what do you think a lab looks like from a student's perspective sort of a day in the life of a typical lab.

SA: Having taken both of the courses with hardware that was dated or what I would consider dated at the time. I think the labsting the overwhelming, because they present so many individual challenges in each of their steps to students. Each individual member goes off on a tangent almost, in order to accomplish part of his individual tasks and returns the team without a cohesive shared knowledge of what the other two members accomplished. And although the courses maybe designed in such a way that in the end everyone joins their knowledge and shares it in some constructive way, in practice with all the other assignments and efforts involved in completing course there's no way for this to feasibly happen.

SA: So because the labs are too overwhelming, the students fail to retain all of the content covered in the course.

NG: Conversely, what is a typical lab look like from an SAs perspective?

SA: So with perspective. I believe that the labs can be trivialized. Especially by some of the more senior members of course staff, myself included. Because you begin to lose the perspective of a student, who doesn't understand all the intricacies of the mechanism. You often can simplify it. Using, you know, your plethora of existing knowledge. And without communicating to the student in detail all of the steps involved in getting the electronics component or mechanism working. They become overwhelmed and confused and I think even scared, working on a lab and I think that causes you know, kind of a bridge of understanding between the senior instructor and the students. I think that they are professors have a better job doing this or do a better job accomplishing this because they have like the educational experience. And I think obviously with time experience you know, course staff will get better hopefully at you know accomplishing these like teaching goals but for now I think that because the components are just too low level and there is too many gaps in knowledge, there's a real barrier in communication sometimes between core staff and students.

NG: Can you call any common pitfalls that you have seen students stumble across during the labs?

SA: So as I mentioned earlier, you know; student's kind of fail to understand each aspect of the individual labs because they are extremely overwhelming, causing students to you know fixate on maybe like one aspect of them. And I think that because, you know labs are all so time consuming and lecture, exams, and quizzes also require out of the lecture hours from students, that the final project is often delayed till the very end. And although they can obtain like a very valuable skill set. Both in terms of theory and practice, you know, the final project ends up being. You know, kind of cut short a little bit. And students can't... never mind accomplish it let alone do the post production analysis and maybe even you know, kind of like feedback steps in order to refine their mechanism and you know, get it to the place that I think the instructors would like it to be. In a fourteen week course any this is easily accomplished, but I don't think that it's reasonable to expect, you know, fourteen weeks to be condensed down to seven.

NG: Are there any common issues that you have encountered as an SA for the this course? If so what were they and how were they resolved?

SA: So I think often times there is a bottleneck during the stressful times during the term on the SA end. In other courses I've seen you know professors handle this exceptionally well, by either varying the schedule of lab due dates or spacing out exams and labs such that you know, the exam week was theory heavy in the lab week was practice light. I don't think that this is the case in the 2000 course series and because of that the scheduling conflicts between course staff and students cause increased our maybe exacerbated detriment to students accomplishing the final project. I think apart from the scheduling there sometimes is a, or can be a barrier in understanding and communication between students and course staff, but I think it's gotten better over the years. I think that the course staff has definitely, you know, come to be a little bit more refined and I think that the a higher level educational staff like the professors, have also you know, tremendously improved over the years. I think that because of that, a little bit those gripes in communication have improved, but are still prevalent none the less.

NG: Do you think that students would be capable of completing the labs on time without help from the SAs/TAs?

SA: No I don't think so because there are too many low level components required in order to accomplish the labs. You have to have a solid amount of knowledge of microcontroller level programming, you also have to be fairly experiencing in electronics hardware and design. So if you have not interfaced with sensors before or lower level electronics components like resistors, capacitors, diodes, Operational amplifiers. Which you do get some experience with in RBE 1001, but not enough to you know kind of pick with and play with\, then you are you fall behind quickly in the course. So basically the students with the most experience can do tremendously well and that becomes kind of like the the baseline for evaluating them so the average student I don't think would be able to get you know each of those individual like mini masteries in order to you know, kind of join our lives together and accomplish it fully. Maybe some students with experience may be able to accomplish the entire lab

all the way through especially if you know the mechanical expert obviously you know, has a mechanical oriented kind of lab. Which can happen in the 2001 course. So I think generally no but I don't think that my opinion holds true for exceptions students.

NG: As an SA, have you ever found it necessary to provide additional information or materials to the students in order to help them complete laps on time? And if you can recall what they were.

SA: Yes absolutely, I think that the documentation for the course is poorly organized thus far. If the labs were a little bit more cohesive, documentation were little bit more... Uniform, then these issues would no longer bite us so hard. I think that because we use components from a number of different vendors and sources and we don't really have a contained kit for students to develop with. We force them to become practice experts you know almost a implementation engineers rather than you know robotics engineers who are studying robotics concepts. And that becomes too much in you know the scope of one course. I think that a seven week course could be devoted to just obtaining skills in terms of both theory and practice in developing, you know, a robotic system as opposed to learning the theory behind a robotic system. So all the content covered in lecture, although may be tangentially applicable to what they do in lab requires additional skill sets that we do not provide students with. We may consider it, we as course staff, may consider it as a prerequisite or knowledge required before taking this course, but again I think that we have to provide them with documentation and examples I guess to fill these lapses oftentimes, or to get them up to speed in order to take a course. Which really again again this is designed for sophomores and entry level students, it's I think it's even recommended that students with significant robotics experience skip right through to 2001 so.

NG: Do you find yourself working more hours as an SA than you are allocated by the RBE program in order to insure that students can see succeed.

SA: Yes! I think that apart from this, The uh administrative department does not respect students. I don't think that it is acceptable if the adult staff here were treated the way student workers are treated here even though we share many of the same concerns especially on the financial end.

NG: How do you feel about the final project?

SA: Although I complained that the final project requires a lot of practical knowledge in terms of being able to accomplish real tasks on real robots. I think it's important that students do learn these skills through the final project. Because the way the course is structured, it's unfortunate that they must learn them in parallel with a lot of the theoretical robotics knowledge that they do obtain both in lectures and in labs and this includes both understanding design and analysis of sensors and mechanisms on the theory end. On the practice end, a lot of the skills that they develop are you really just through putting the time in. And because the students are already short on time, the final project ultimately is a disservice and I think it takes away from what they could learn on the theory end and add then adds a little bit on the practice end without them being able to fully dive deep into it. To use poor language, it's kind of half A\*\*\*\*\* two things.

NG: How do you feel about that CDR and PDR process?

SA: Personally I think the CDR and PDR have potential to be very constructive, however as a student I took a very lightly and find that as core staff students treat them very lightly and don't. Properly prepare their presentations, understand their mechanisms prior to designing to them. And they could really use that feedback obtained during the PDR to refine their final designs and you know implement the proper analysis steps. The advice given by especially the professors in accomplishing this final project is phenomenal, but again because the PDR/CDR aren't really graded students don't take them seriously. They, you know, put it on the very back burner. And you know rush into their PDR/CDR having done their presentation the previous hour without really knowing what's going on. And I think that they ultimately way the final project presentation much more even though it should be really, you know, kind of building one off the other. The PDR into the CDR into the final project presentation. And the students who don't do that successfully don't think demonstrate the analysis steps, so again, it causes lapse in knowledge. If it were graded I think that students would definitely more effort into it. I think we pulled back from other aspects of the course made it significantly, you know, proportionally way more students can achieve you know those understandings of analysis of mechanisms and you know, even for that the design of mechanisms for the PDR done right in order to get you know the knowledge that professors want without adding additional workload to the students.

NG: In your experience, do students usually finish the final project on time?

SA: By majority no. In my case as a student I was just barely able to finish both projects. I believe that I had a very low success rate. Maybe only about thirty to forty percent on the runs of each of the final projects. I think that if the designed of the challenge itself were improve the success rate would be higher because you know in 2001 particular the challenge itself doesn't really lend itself to this theory taught in the course which is four bar linkages. I know that there are changes that are to be made to this final project. I have very high hopes for them. So I hope that you know that you thousands although again it gets pretty topically relevant. I think it be a little bit more refined by giving students you know. A wider choice or maybe you know uniform but wide choice of sensors that they could use to accomplish the task because right now I'm kinda seems primarily that you know use some type of distance sensing or your sophisticated enough to use a camera and it causes kind of like a binary split between you know, the more sophisticated more advanced group of students use the sophisticated

mechanisms and the students who simply lack the experience are forced to use dated hardware that requires a lot of implementation time.

NG: All right. That is all of our questions. Is there anything else that you would like to be known or stated on the record?

SA: Right now I think that the RBE 200X course series does a poor job of really bridging the gap between a robotics student who lacks design and implementation experience from RBE 1001 which again is a course that's similar super overloaded in terms of content causing students to really like stress for time favoring the students who are most experience and I think that ultimately causes you know, larger gaps in the system at the 300X and MQP levels of the Unified Robotics program and in the undergraduate program respectively here at WPI. I think it's really important that you know this work be done in order to refine the system such that robotic students are becoming better and better engineers. It's really disheartening to me that you know, this school has not provided the rigorous structure and resources that you know a lot of the other departments here get but you know uses WPI Robotics very much for its attractive features and that's marketing in STEM and sourcing grants things that you know are big important problems for major universities to solve. WPI seems to be really taking advantage of it. I mean it's important that this project and other it continue to develop these courses because this is the level at which the most improvement can be made for the greatest number of people. Thank you so much for allowing me to contribute to your project I hope it made it better.

NG: And thank you for your time.

## Appendix H: Student Interviews

### Student Interview #1 - 1/17/18

NG: Just for the record could you state your name and graduating year?

S1: REDACTED, 2020.

JR: And when did you take 2001?

S1: A17

NG: How do you feel about this course?

S1: Uh, it was a lot of work I mean, some of the, The organization was alright it was just a lot of material, and the labs sometimes didn't work, or people didn't... 2002 was the one where it really didn't work but there is some stuff that I remember didn't really work for 2001.

NG: What is your opinion of the design reviews (PDR/CDR)?

S1: I mean like um. They were useful but I remember my group, we got really prepared. Some of the stuff was weird requirements like especially the full force thing for the linkage. We spent like a lot of time doing that. And we were like really confused and didn't really help us that much besides for the requirement for the final report.

NG: Did you change your final design as a result of the design reviews?

S1: Not drastically, maybe like minor changes that I don't really remember but there wasn't, we didn't make any sweeping changes to our robot because of those.

S1: What weaknesses do you see in the labs?

S1: Mainly like the lack of functioning equipment or stuff just not working. You know I mean. My kit was missing a bunch of parts. A lot of peoples kits were missing parts or broken parts. It would just make big hangups or we would need to figure out something that wasn't explained well or it would take forever.

MC: Do you remember anything specific that you didn't have or was broken?

S1: Not specifically from 2001, Yeah it was too long ago and 2002 was in between that.

JR: You mentioned thing not being explained well. Can you remember anything specifically not explained well?

S1: I would need to look at the labs again I don't remember exactly which.

JR: OK, What strengths do you see in the labs?

S1: I mean a good chunk of them were valuable for the final project. I remember the Bluetooth one gave you basically like the code to use like for the Bluetooth communication. That was useful, I mean I knew the stuff that happened in and I knew how to use that stuff for them but I think for me it was valuable and I think for a lot of other people it was valuable. Um Im trying to think of the other labs. The one for PID control was kinda useful as well. I mean I already knew how that worked but it helped me solidify some of the code.

JR: What strengths do you see in the lectures?

S1: The lectures contained a lot of information that was good. Basically they were really informative for the time spent in there.

JR: What weaknesses do you see in the lectures?

S1: There was a lot of information. No, its uh, its just a lot to learn.

JR: What strengths do you see in the final project?

S1: It was a good change for a very programming heavy, it was design heavy, but like the program, doing a set of tasks, kind of changing around the order or number of them. That was something I hadn't really done before. That was some really necessary experience going forward and like getting all those little functions to play nice and work properly.

JR: What weaknesses do you see in the final project?

S1: I mean some of the stuff was temperamental. I mean the bluetooth was temperamental for me. It was a good thing I had it. You know sometimes it would work sometimes it wouldn't. I mean the. I heard at least the app was much better this year than last year. Sometime like one thing just wouldn't work. It would work one way but then wouldn't work another way. That kind of stuff.

JR: What do you think a lab looks like from a S1's perspective in general?

S1: Go to lab. Try and get as much done as possible. Something won't work so skip that. Hope an SA can help you if they can't. Then you'll probably finish like a chunk of the lab anywhere from a quarter to a half depending on how well it goes. Come back, bust it out later, hopefully everything work if not come back when there is an SA or get an SA for help. Hopefully figure it out with them. And then at that point crank out the rest of the questions and hand it in.

JR: When you say hopefully something works, could you elaborate on that?

S1: I could think of a couple instances where ... you have to get a specific reading on an oscilloscope and it just doesn't do that reading. I mean I can't remember exactly. It happened a couple times in 2001 I don't remember exactly the reason, but it was like some component was acting weird or just not functioning. Or the oscilloscope just wouldn't just do exactly what we needed. So we would have to ask an SA and they might not know, so they would get another one. Or we would just skip it and come back to it later. Stuff like that.

MC: You said that after you have the lab period you go out and crank it out afterwards. How long do you think that would typically take?

S1: I mean we'd as far as in lab time goes we would usually spend at least another two hours working on the stuff in lab. Now that could go on longer if stuff became more difficult or less cooperative but as far as like in lab work we would spend an additional two hours finishing that.

MC: And out of lab work?

S1: That was probably another two hours or so you know to get all the data compiled and presented in a reasonable way.

JR: So how do you feel about the lab experience as a student?

S1: I mean, I think, I didn't like it. Mostly because there was a lot of work I had to make sure that you know I was taking. I basically have to dedicate a large block of time to working on RBE labs. I need to plan my schedule. Like my course load around that. You know I couldn't take a course with another significant lab component because RBE takes that up.

JR: Is there anything that you feel that we did not ask that you would like to be known?

S1: No

MC: One other question just for clarification. How long do you think each lab would take. You know, total time?

S1: Total time was probably around 6 hours. You know it could go shorter if we got lucky or you know could go longer if certain issues didn't get resolved.

JR: Does that include in lab time?

S1: Yes two hours scheduled lab, two hours of lab, two hours working on it. Yeah that adds up to six .

JR: Thank you for your time.

## Student Interview #2 - 2/8/2018

NG: Alright so just for our purposes could you state your name?

S2: I am REDACTED

NG: And are you okay with this interview being recorded, transcribed, and possibly included in our IQP report?

S2: Completely fine.

NG: All right how do you feel about the course being two thousand one, RBE 2001?

S2: 2001 was incredibly difficult, I don't think I would have passed if I hadn't been blessed with very smart friends.

S2: Part of the problem I found was that I just didn't know enough about robotics I don't know if that was a problem with one thousand one being less of an intro course than I imagined, but...um. I learned quick.

S2: I felt like I was missing stuff like statics and free body diagrams which would have helped out a lot more it was just a quite gruesome jump from 1001 one to 2001.

NG: What is your opinion of the design reviews the CDR and the PDR?

S2: I just have to refresh what those were in my head. Those were... All right. As far as I can remember. I think the worst part about that though was it just required us to be incredibly on point and plan out everything from week one. If we had not done that, it would be a lot worse and I had a friend who had less of an on point focus team and had to drop the class because of it.

NG: Did you change your design as a result of either of these design reviews?

S2: Our design was pretty on point for the whole thing we had just spent a lot of time eking out the design. Weeks ahead of schedule so, this is part of where I did I'm sort of weird because I'm not especially gifted at robotics I was just with friends who are incredibly good at it and so they really helped me out. Despite everything I was capable or incapable of doing. So yeah, we survived past those things.

NG: Alright, and now that the next questions are going to be kind of repetitive it's going to be pairs of questions about different subcategories of the class. So, to start off, what strengths did you see in the labs?

S2: The strength I saw in the labs? Well for one, the TAs are always really great in those labs because if they don't know what you're supposed to be doing they will agree with you that it's really dumb that you're supposed to be doing that and that, like at least gives you an inkling of where to go and also just feel better for not getting the subject. Besides that, I enjoyed it a lot more than Intro to robotics where we had the over looming final project but then we also just had all this. No way, I remembered the labs it was still like that. I have a lot more to say about disliking the labs...

NG: You can go ahead and move on to that section now

S2: What I disliked about the labs, for one, the set up of having an over looming final project which is overwhelmingly the most important thing about your grades and then sprinkled in with all these labs testing specific things. Really hinders your ability to make that final project, and some of the stuff was useful. But other parts was just so much information for something we would never use. I think. I think it was the Bluetooth one. was the most annoying - well actually I think it was the final free body motion one which we couldn't finish because they just required so much of us and we didn't have enough time. So that constantly sort of undercutting your grade in time for the actual final project instead of giving you things that would aid along the way was kind of infuriating

NG: Perfect. What strengths do you see in the lectures?

S2: I felt something good about the lectures is that, when it's clear that people are really lost on the subject, the professor can usually give something, an analogous situation that can help understand what's going on. I would say that the lectures in tandem with the videos that he often sends out. It's a useful way to sort of be engaged outside of class because usually lectures can sort of go in one ear and out the other but having this sort of combined front helps it to keep fresh in your mind. Which I think helped with retaining information for the most part.

NG: Can you recall any problems or weaknesses that you had with the lecture section of the class?

S2: well, And this is not a new fact that the lectures can sometimes go slow and a bit monotonous and I specified that when prompted he could give really helpful comparisons. Those did not happen all that often. That might have been also a fact of the class relatively being silent for awhile. But. Beside sort of just the vagueness there is usually a lot of depth going relatively quickly to slide to slide just a lot of information, and despite how slow he'd usually go there's no way you can glean most of everything you need from that slide before it goes on and then you have to check the computer to see the slide he pulled up and then you're already behind.

NG: Moving to the next section, what strengths did you see in the final project?

S2: The final project is something. I always enjoy when we do it because it's just free reign to solve a problem. And I think having that light guidance of "all right well you're on a good track this. From what I can see from the information what you've presented it seems like you're on a good route to actually completing your goal" I thought the check ups were really useful because, what I like most about these sort of project ones is that it's very one on one with the teacher. It's not so much a grade as feasibility. Which I appreciate. And it's a more hands on sort of learning which is something I really enjoy.

NG: Conversely what weaknesses do you see in the current project?

S2: I mean of course there's time but there's nothing you can really do about that. As mentioned before mixed in with the labs that makes it difficult mix in with the homeworks it makes it difficult to find time for a lab, especially with all your other classes.

S2: I think it's more of the group dynamics can become a little strained and dicey in these classes just because of the student body that takes robotics.

S2: I don't think that something we can really control but. I'd say I can't find really any problems besides time and that just building a robot is difficult, and so it requires a lot of facets to sort of come together not everyone can be good at all of those things.

NG: Moving on, what do you think a typical lab looks like from a student's perspective sort of like a day in the life of a lab session.

S2: Well what I can recount is first of all you wake up early in the morning miserable because you have to lab. You sit around for a little bit and then you get told that whatever's thing you're supposed to do, your objective. And then you're able to maybe fill out your sort of guideline maybe complete the data you need to get for that class. Hopefully you finish in the time period sometimes a little early that's a bonus because you get breakfast, otherwise you'll just have to regroup and my main problem with the labs that took here, is, some labs bleed over and it takes a couple hours outside of lab to finish. A lot of these labs take probably three times as long as they really need to. With what you have to do. It shouldn't be that every week you're going down to the wire to complete your lab. That's at that point your lab might just be a bit too long.

NG: Perfect. Is there anything else that we did not ask you that you'd like to be known?

S2: I will say from the standpoint of someone who had never taken robotics before one thousand one, I don't know if I was necessarily equipped for this. That might be a little onus on me but that is something I was sort of upset about there seems to be. And I mean it's fair that there's an assumption that everyone who takes these has a pretty good understanding of how robotics works and how does machinery and just how to tinker. Which makes sense but so are frustrating for that 'n' percent who doesn't.

NG: Can you recall any like specific like topics that you remember struggling on?

S2: It's a lot of stuff like knowing motors, just knowing the correct procedures for programming a motor or just setting up the stuff using Allen wrenches knowing which is just more hands on tools. Or just design. I feel like I had something but I can't really remember. I remembered the quizzes sucked, I hated them so much. I think I passed two of them and I know that a lot of people that did well on them and I also know a lot of people who dreaded them just as much as I did.

NG: Anything else?

S2: Not besides glad I can hopefully help to make this class better.

NG: Thank you for your time.

### Student Interview #3 - 2/26/2018

NG: Alright for the record could you state your name?

S3: My name is REDACTED

NG: And when did you take RBE 2001?

S3: C-term 2017

NG: And are you okay with this interview being recorded, transcribed, and possibly included in our IQP report?

S3: Yes, I am.

NG: Alright, how do you feel about this course?

S3: I feel like the course tried to jump into a little bit too much. There are too many like, two or three day crash courses and then put that straight into a lab without time to actually learn the material.

NG: What is your opinion of the design reviews, the PDR and the CDR?

S3: I really like their timing for that course. They make sure that you did everything out in advance. They're just really helpful.

NG: As a result of them did you change your design?

S3: Yes we did. In the PDR we realized that the mechanism we had all planned out and CADed, it just wasn't gonna work. I couldn't get certain positions, so we had to completely redo that. We might not have realized that until much later without it.

NG: Alright, the next section of questions is going to be a set of three in different categories and the pros and cons on each one, I'm just preparing you because it's like a big block.

S3: Okay.

NG: So, what strengths do you see in the labs?

S3: I mean the labs can be a really good way to apply the material you learned in class and see how it relates to a robot construction and how you would use some of the mechanisms and the calculations to find useful information, to plan out things.

NG: And conversely, what weaknesses do you see in the current RBE 2001 labs?

S3: From what I recall, a lot of them were kinda vague and confusing. A lot of time spent figuring out what we had to actually do, before jumping into it, a lot of that was because of not fully understanding the material.

NG: I know it was a long time ago but, can you recall any specific instances of perhaps like a side tangent or something you got distracted on where you didn't understand the lab so you like worked on something? And it wasn't necessarily making progress. If not, that's okay, it's a very specific request.

S3: I mean, I'm pretty sure that happened, but I can't remember a specific lab when.

NG: Moving on, what strengths do you see in the lectures?

S3: Well, they covered a wide range material and some of the topics, mainly more the basic stuff of four bars really got driven in a lot because it got elaborated on. Then some of the really continuous topics went throughout the entire course. I guess specifically four bar mechanics and everything, going a step further every time, plotting out all the exact motion.

NG: And conversely, do you recall any weaknesses? In the lectures.

S3: Pretty much the exact opposite.

S3: Like most other topics were touched on and not really delved into.

S3: And then the really quick turnaround on all the labs to have all that on the tests again. Not quite enough time for practice.

NG: Alright, so moving on to the final project, what strengths do you see in the current final project?

S3: Well ideally, it's what it's meant to be, kind of a capstone of all the covered topics.

S3: That about it.

NG: And then moving on, what weaknesses or problems do you see with the final project?

S3: The biggest one is Bluetooth.

S3: While I think it would be fine to implement if it was all functional most the time. Most of the time, we didn't know whether the Bluetooth chips were working. My team couldn't actually ever test Bluetooth until the day before the final thing because we could never get our hands on a working chip at all. Which hurt a lot because we couldn't legitimately test the robot until then.

NG: Alright, moving on, what do you think a lab looks like from a student's perspective? Sort of a day in the life of a student, what happens going into the lab, or working on lab outside of lab section.

S3: Like.

S3: Just kind of planning out for..?

NG: Yeah just sort of like describe like the experience of like maybe one lab.

S3: Okay.

NG: In vague terms.

S3: Like one lab session or?

NG: Like a week of doing a lab

S3: Okay.

NG: What would that look like?

S3: Normally it's going in on Wednesday and figuring out what the lab is about, and then trying to get a chunk of it done.

S3: And the majority of the work is done outside of that first session of course because it's just two hours.

S3: Ideally for me that would be going to the lab pretty much every day, doing a few hours. That didn't work out that way for 2001 because of my team and scheduling dynamics.

S3: But I would want to do small chunks over the course of the week and get, you know it could take 15 to 20 hours to finish them.

NG: Alright, good.

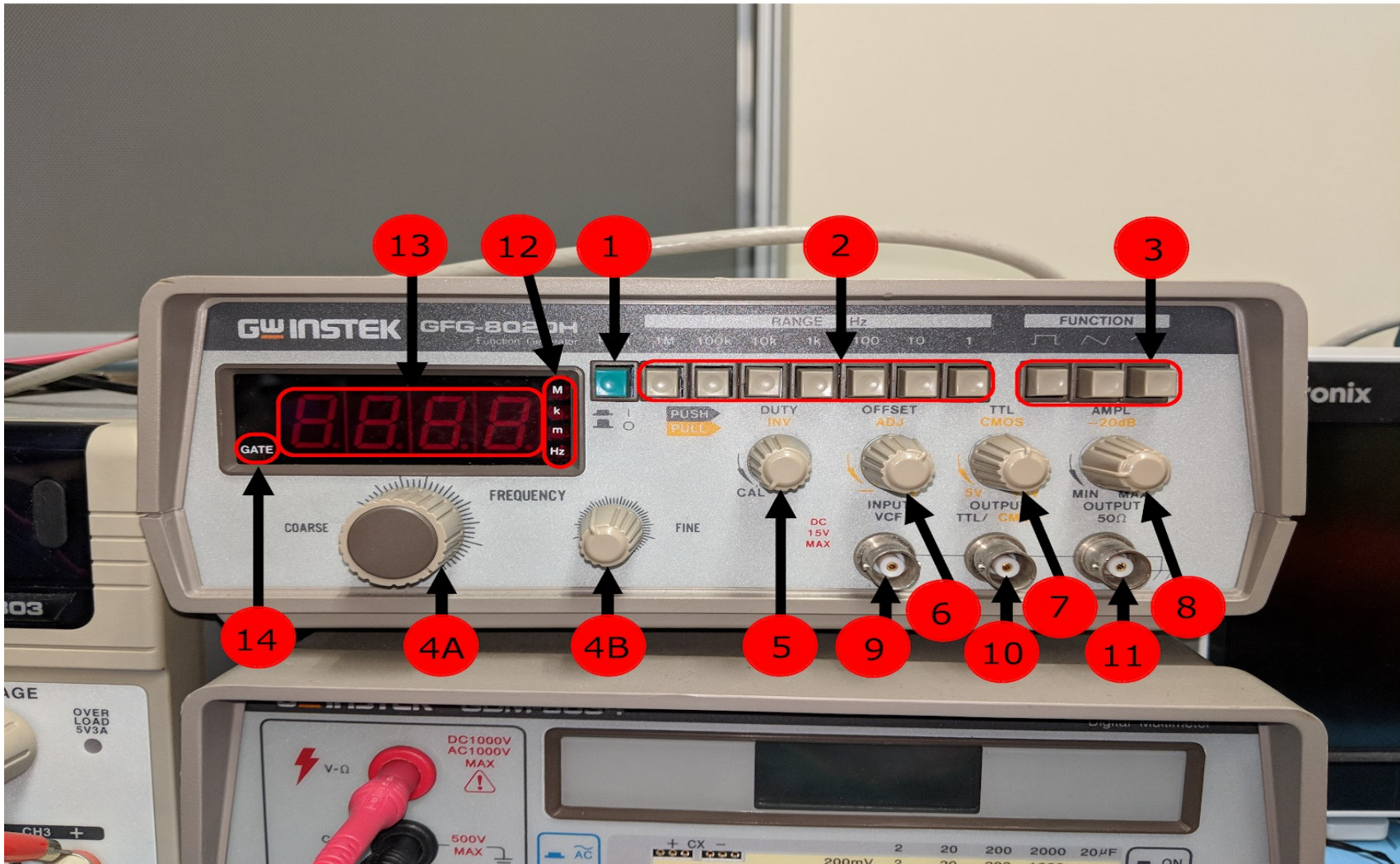
NG: Alright that's the last question, so is there anything else that you feel that we didn't cover in these questions that you would like to be known officially on the record for this IQP.

S3: No, I don't think so.

NG: Thank you for your time.

Appendix I: Function Generator

# GW INSTEK GFG-8020H Function Generator





Item Label and Name		Description	
1	Power Switch	The power switch turns the device on or off. When the button is depressed the device will be on.	
2	Range Selectors	This bank of switches is used to select the frequency range of the output signal. Only one frequency range may be selected at a time by pushing the button corresponding to the preferred frequency range. A selected frequency switch will become raised when another frequency is selected.	
3	Function Selectors	This bank of switches is used to select the desired output function type (Square, Triangle, and Sine). Only one function may be selected at a time by pushing the button corresponding to the preferred function. A selected function will become raised when another function is selected.	
4A	Frequency Adjustment Knob COARSE	This knob adjusts the output frequency of the waveform over a wide range, but with less precision than the Fine Frequency Adjustment Knob.	
4B	Frequency Adjustment Knob FINE	This knob adjusts the output frequency of the waveform over a narrower range, but with more precision than the Coarse Frequency Adjustment Knob.	
5	DUTY/INV Knob	PUSH: While this knob is pushed in the knob controls the duty cycle of the waveform ranging from 50% to 100%.	PULL: While this knob is pulled out the output will be inverted; the knob will now control duty cycles between 50% and 10%.
6	OFFSET/ADJ Knob	PUSH: While this knob is pushed in the DC offset is disabled.	PULL: While this knob is pulled out ADJ (Adjustment) control is selected, allowing the user to control the DC offset of the output waveform.

7	TTL/CMOS	PUSH: While this knob is pushed in TTL is selected as the output signal type for the TTL/CMOS output (#10).	PULL: While this knob is pulled out CMOS is selected as the output signal type for the TTL/CMOS output (#10). This knob provides CMOS Level Control from 4V (+/-1V) to 14.5V(+/-0.5V).
8	AMPL/~20dB	PUSH: While this knob is pushed it provides attenuation control of the output waveform ranging from 20dB to 40dB.	PULL: While this knob is pulled out it provides attenuation control of the output waveform ranging from 0dB to 20dB.
9	INPUT VCF	The Voltage-Controlled Frequency Input is provided to allow for external control of frequency sweeping. A supplied voltage of +10V will result in the frequency being swept down to 10:1. A supplied voltage of -10V will result in the frequency being swept up to 1:10.	
10	OUTPUT TTL/CMOS	The TTL/CMOS Output is provided as the source of the TTL and CMOS signals. One of these signals will always be selected as a result of the position of the TTL/CMOS knob (#7).	
11	OUTPUT 50Ω	The 50Ω Output is the generic waveform output, it is the source of all of the waveforms other than TTL and CMOS. 50Ω is the internal resistance of this output circuit and should be accounted for when using this device.	
12	Units Indicator	Displays the current SI prefix corresponding to the current waveform frequency	
13	Counter Display	Displays the current internal frequency of the waveform.	
14	Gate LED	The Gate LED signals when the function generator is sampling the produced waveform to update the frequency display.	

For more information on TTL and CMOS logic, Sparkfun has created good educational material on these subjects.

Sparkfun TTL logic: <https://learn.sparkfun.com/tutorials/logic-levels/ttl-logic-levels>

Sparkfun CMOS logic: <https://learn.sparkfun.com/tutorials/logic-levels/33-v-cmos-logic-levels>

GW INSTEK. (1998). *Digital Function Generator Model: GFG-8020H: User Guide*. Retrieved from [http://www.gwinstek.com/en-global/products/Signal\\_Sources/Analog\\_Function\\_Generators/GFG-8020H](http://www.gwinstek.com/en-global/products/Signal_Sources/Analog_Function_Generators/GFG-8020H)

## Appendix J: New Final Project Description

### Transport of Objects in a Robotic Storage Facility

The final project task is to simulate an autonomous robot tasked with transporting various objects around a storage facility. Figure 1 shows a schematic layout of the storage facility's Robot Operating Floor. This resembles what you would see if looking down from above.

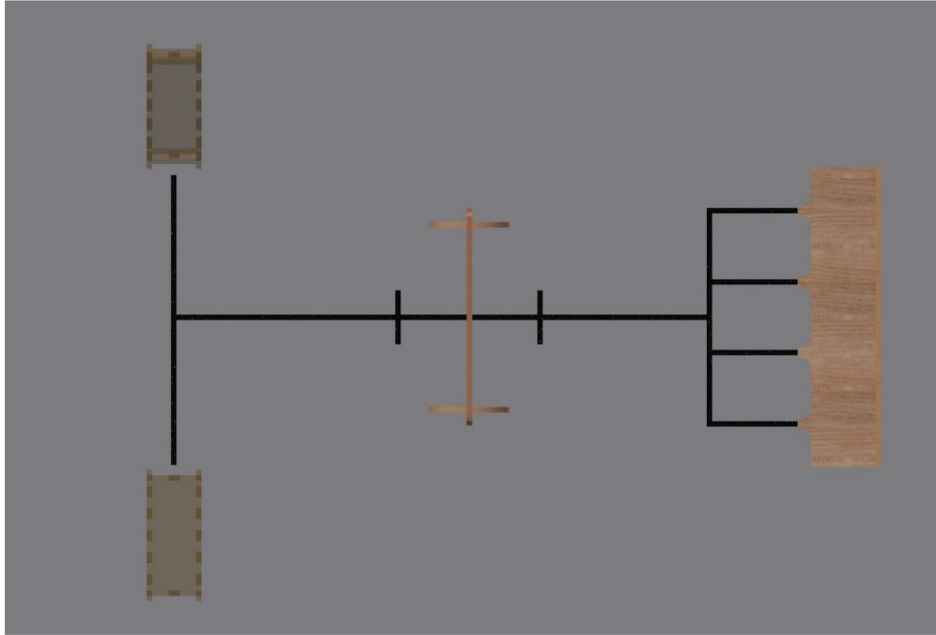


Figure 1: Robot Operating Floor

There are four sections of the Robot Operating Floor: Long Term Storage, Pick Up, Drop Off, and the Gate. The Drop Off location is a long smooth trough that is four (4) inches wide and ten (10) inches long with one (1) inch high walls surrounding it. The Pick Up location is a long trough tilted at 30 degrees, four (4) inches wide, and ten (10) inches long with one (1) inch high walls surrounding it. The Long Term Storage location is a four wide by three tall set of Storage Slots that is used for long term storage of materials not currently requested by the storage system. The Pick Up location will start with either one or two objects that must be brought to Long Term Storage. The Drop Off location will start with nothing but will contain object(s) as a result of a successful robot simulation. These three locations have no form of visible signal for when any of their Storage Slots are filled. Storage Slots are six inch cubes (when measured from the interior). The Storage Slots for Long Term Storage each have one side removed, exposing the inside to the Robot Operating Floor, this allows for robots to place and retrieve objects from Long Term Storage. The Gate is a structure with a 14in wide and 10in tall opening centered on the line connecting Long Term Storage to the Drop Off and Pick Up locations. There is a marker preceding the Gate on either side by six (6) inches as a warning to any approaching robots on the Robot Operating Floor. Any part of a robot that moves in relation to the field must fit through this gate. Any part of a robot that does not move in relation to the field will be considered a Field Augmentation. Field Augmentations must not damage the field and must be able to be set up and taken down easily, requiring no more than five (5) minutes for each process.

## Transport of Objects in a Robotic Storage Facility

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Briefly, the robot needs to:

- Navigate to the Pick Up location,
- Remove an object from the Pick Up location,
- Signal that they have possession of the object,
- Navigate to Long Term Storage,
- Store the object in the designated empty Long Term Storage Storage Slot,
- Signal that the object is now in Long Term Storage,
- Remove the requested object from its corresponding Long Term Storage Slot,
- Signal that they have possession of the object,
- Navigate to the Drop Off location,
- Place the requested object in the Drop Off location,
- Signal that the object has been placed in the Drop Off location.

Task Details:

- The operator can drive (tele-operate) the robot up to a Storage Slot. This tele-operated driving is taking place via a high-bandwidth, real-time video connection from a camera onboard the robot.<sup>1</sup> A V-shaped notch on the front of the robot is allowed to gently push against the alignment guides in front of each column of Storage Slots in Long Term Storage. The objects used for this simulation will be no larger than a three inch cube, but will be larger than a two inch cube. See Appendix A for details.
- The robot needs to autonomously remove the object from the Pick Up location. The robot will need to use a vertical pull of a few inches in order to have the object clear the walls bordering the Pick Up location. *Points will be deducted if the object substantially rubs against the walls of the Pick Up location during object removal* (such rubbing may damage the object and increases the cost to remanufacture/dispose it).<sup>2</sup>
- When the object has been removed from the Pick Up location, tele-operation is no longer possible. This is due to the object blocking the view of the camera, such that the notional remote video operation of the robot is no longer possible. Field communications are still possible though – see below. The robot now needs to autonomously navigate its way to the designated Long Term Storage location.
- The Storage Control System (i.e., the playing field control computer) will communicate to the robot as to which Storage Slot the object is to be stored in.<sup>3</sup>
- The robot needs to lift the object to the correct height and align it with the empty Storage Slot; the object can then be inserted into the Storage Slot. Physical alignment devices will be available on the playing field to aid the robot in getting properly lined up with the Storage Slots.

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<sup>1</sup> The camera and video link is notional. We do not have sufficient resources for each team to have such a camera. Robot drivers will instead use their Mark II eyeballs to simulate the camera while tele-operating the robot.

<sup>2</sup> We will supply servos to each team in the kit of parts. The team may design and use a gripper using this provided servo if they wish.

<sup>3</sup> Just to make it more interesting, other message types will also be broadcast. Robots should additionally be aware that messages may be directed to other robots working in the area, so they need to pay attention only to messages addressed to themselves as well as those broadcast to all robots. See the message packet protocol for more details on robot addressing.

## Transport of Objects in a Robotic Storage Facility

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- Having stored the object, the robot may once again be tele-operated to pick up a requested object from Long Term Storage. Optionally (and for additional credit), the robot can autonomously navigate to the requested objects location. As before, the object will block the camera once the object has been removed. The robot must therefore autonomously navigate its way to the Drop Off location.
- While the robot is in possession of an object, the robot must continuously display a visual alert (at least a flashing red LED). It should also broadcast 'Object Possession' messages over the field communications channel for additional credit.
- If using field communications in any way, a robot must respond as appropriate to all messages. These could be messages broadcast to all robots, or it could be a message sent to a specific robot. The 'address' for each robot is your assigned team number. See the message protocol for details. Successful responses to field communication messages (when appropriate) will result in a point bonus.
- An actuation mechanism is required to be incorporated into the robot in some way. It should be used in a way that is meaningful and important to the operation of the robot. This actuation method must be approved by course staff before implementation in order to count towards this requirement.

### Scoring:

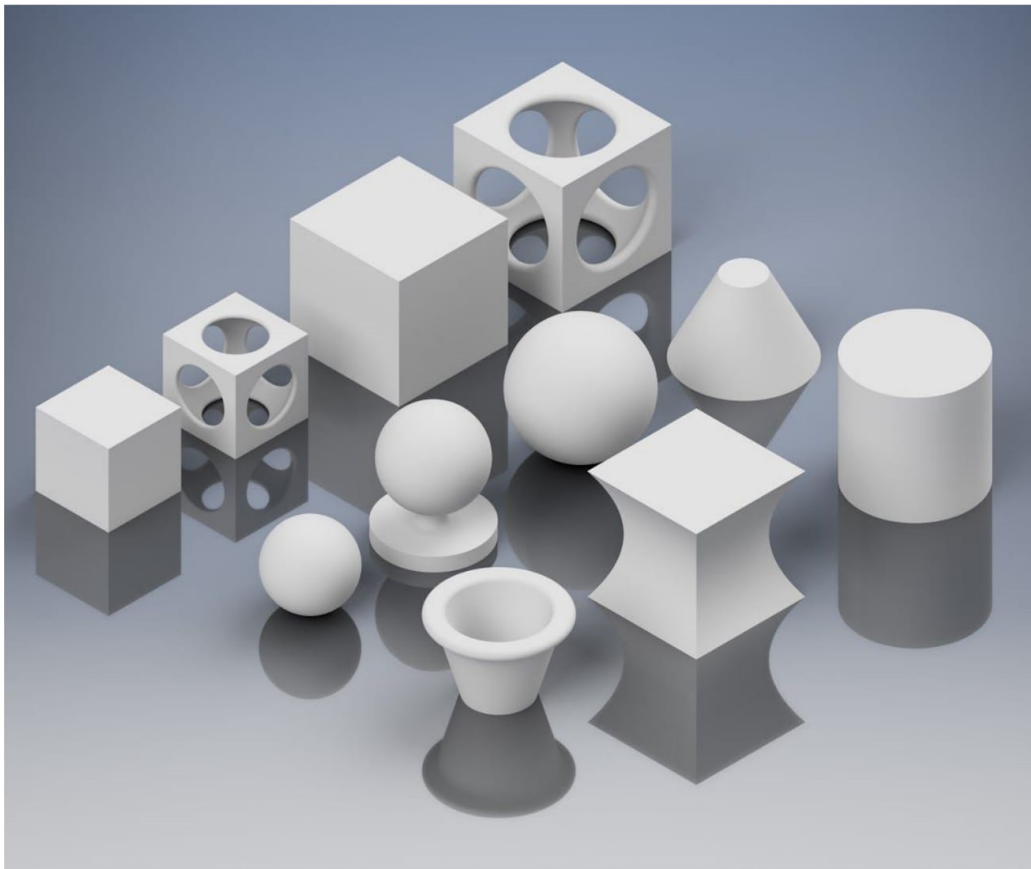
There will be an overall time limit of 10 minutes for the game. The goal is to score as many points as you can during that time. Points are awarded or deducted as detailed in Appendix B: Scoring Rubric.

### Project Goals:

- Require use of most of the material taught in RBE 2001 as well as material previously learned in RBE 1001.
- Demonstrate good software development and coding practices.
- Deal with a mix of autonomous and tele-operation in the robot tasks.
- Use field communications for autonomous interaction with the Storage Control System (e.g., the playing field control computer). A simple message-packet protocol has been defined to accomplish this. See the separate Field Communication Protocol document for details.
- Demonstrate understanding of and an ability to use a simple message packet protocol (regular structure, addressing, checksums, etc.).
- [ Optional ] Use field communications for debugging of untethered operation.
- Provide an opportunity for and encourage the use of:
  - an actuation mechanism for a useful function
  - other mechanisms as appropriateto attain the different required orientations of the objects (vertical and horizontal).
- Demonstrate, encourage and require good technical communications in the form of:
  - Supplied project documents
  - Informal preliminary design review
  - More formal critical design review
  - Final formal project presentation
  - Final formal project report
  - Demo of the robot in action

### Appendix A: Object Types

- 2in cube
- 3in diameter
- 2in tall cylinder
- 3in cube
- 3in sphere
- cone shape
- small plant pots
- other objects at the course staffs discretion



## Transport of Objects in a Robotic Storage Facility

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### Appendix B: Scoring Rubric

Category	Description	Score Range	Perfect Score	Weight	Totals
Overall Design	How well does the overall design work towards accomplishing the project goals? (Overall design is clearly intended for the project (4) / Overall design lends itself to final project but some aspects seem misguided (3) / Overall design is misguided but still works for the project (2) / Some aspects of overall design work towards project goals but most of the design is extraneous (1) / Overall design appears to be for a different project entirely (0))	0 - 4	4	5	20
Innovation/Creativity	How much innovation and/or creativity is evident in the design? This could include hardware as well as the control algorithms, e.g. software. (Very creative and innovative (3) / no innovation or creativity apparent (0))	0 - 3	3	5	15
Reliability - mechanical	Rate the reliability of the mechanical aspects of the robot. (Solid design execution and functions properly (3) / occasionally needs repair or reset to function (2) / constantly in need of repair or reset to function (1) / no functionality (0))	0 - 3	3	5	15
Reliability - control program	Rate the reliability of the control (software) aspects of the robot. This is from the observed behaviors. The code itself (design / structure / commenting) will be separately reviewed as part of the final report. Score: 0 = poor → 3 = excellent	0 - 3	3	5	15
Mech - Actuation requirement	The robot is required to have an approved actuation mechanism. (not present (0) / present (1))	0 - 1	1	15	15
Mech - Actuation Mechanism use	How central to the operation of the robot is the actuation mechanism? (not present (0) / present but not central (1) /very central (2))	0 - 2	2	5	10
Mech - Dynamics	How well were forces/torques accounted for? Does the design indicate an awareness of and attempt to deal with forces, moment arms, etc.? (not accounted for (0) / attempt was clearly made (1) / all forces/torques are accounted for (2))	0 - 2	2	5	10
Mech - End Effector Design & Operation	Is the end effector design suitable for the task? How well does the end effector work? Does the end effector design detract from its operation? (end effector inhibits robot functionality (0) / end effector is present but does not affect robot functionality at all (1) / end effector works well but not for all objects (2)/ end effector works flawlessly (3))	0 - 3	3	5	15

## Transport of Objects in a Robotic Storage Facility

Electrical - neatness	Has there been an attempt to tidy up the wiring and keep it neat? Labeling wires should add to this score (but not detract if not present). (no attempt(0) / some neatness (1) / no room for meaningful improvement (2))	0 - 2	2	5	10
Pick Up Removal	How well was the object removed from the Pick Up location? not attempted (0) / object removal is attempted, but not successful (1) / large amounts of jostling (2) / minor bumping (3) / flawlessly (4)	0 - 4	4	5	20
Drop Off Placement	How well was the object placed in the Drop Off location? not at all (0) / object placement is attempted but not successful (1) / large amounts of jostling (2) / minor bumping (3) / flawlessly (4)	0 - 4	4	5	20
Object holding	Was an object dropped during the demo? (Yes (1) / NO (0))	0 - 1	0	-20	0
Specified Long Term Storage Storage Slot	Object was placed in the specified Storage Slot in Long Term Storage (Success (2) / wrong Storage Slot (1) / failure (0) )	0 - 2	2	15	30
Stowing ability	Object is completely contained by Storage slot that it has been placed in (success or failure)	0 - 1	1	20	20
Navigation from Pick Up to Long Term Storage	Was the robot able to successfully navigate autonomously to Long Term Storage from Pick Up? (Success (1) or failure (0) )	0 - 1	1	20	20
Navigation from Long Term Storage to Drop Off	Was the robot able to successfully navigate autonomously to Drop Off from Long Term Storage? (Success (1) or failure (0) )	0 - 1	1	20	20
Response to "All Robot" messages	Does the robot respond appropriately to messages directed at all robots? (Success (1) / Failure (0) )	0 - 1	1	5	5
Response to "Robot Specific" Messages	Does the Robot respond appropriately to messages directed to specific robots? (Success (1) / Failure (0) )	0 - 1	1	5	5
Object Possession Alerts	Does the robot transmit messages stating that it has an object in its possession when appropriate? (Success (1) / Failure (0) )	0 - 1	1	5	5
Heartbeat Messages	Does the robot transmit heartbeat messages when appropriate? (Success (1) / Failure (0) )	0 - 1	1	5	5
Time used by team	Should be less than 10 minutes. -1 score for every minute over		0	-5	

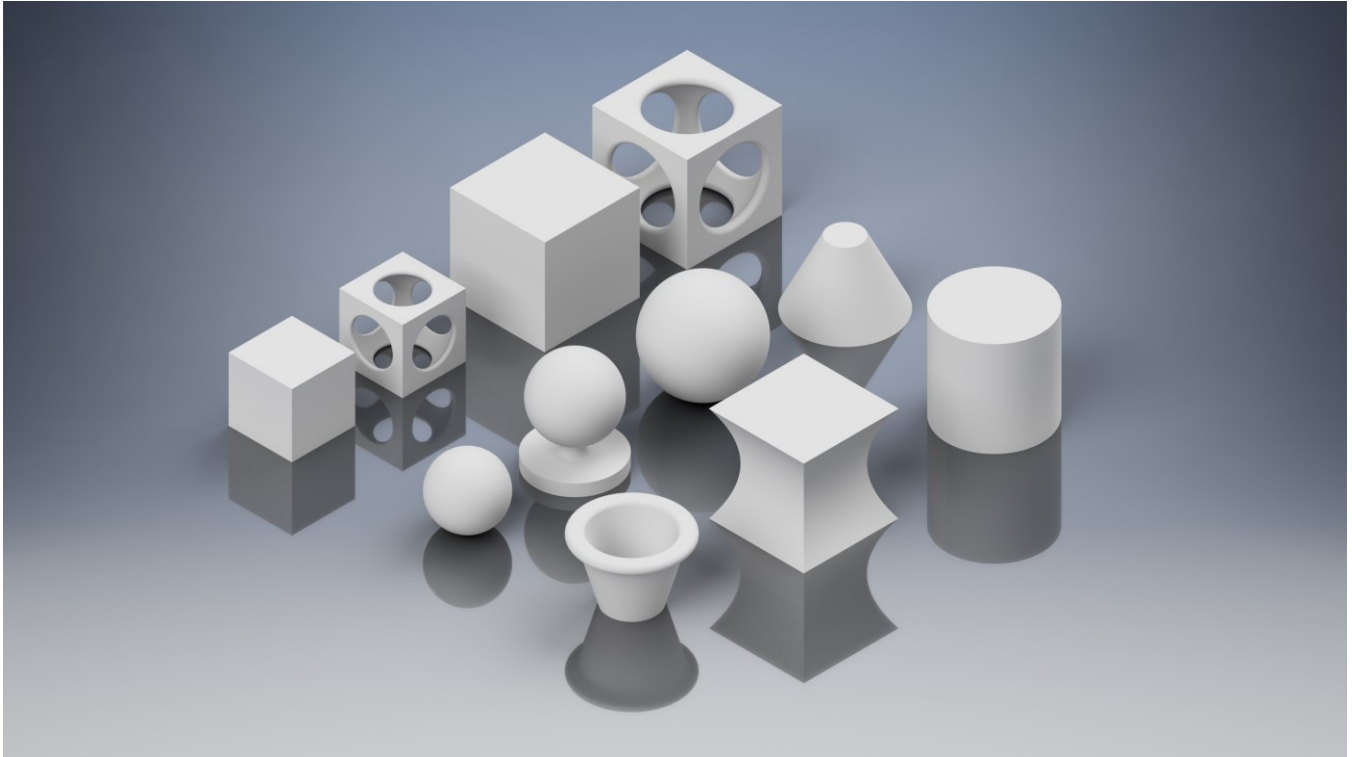


### Transport of Objects in a Robotic Storage Facility

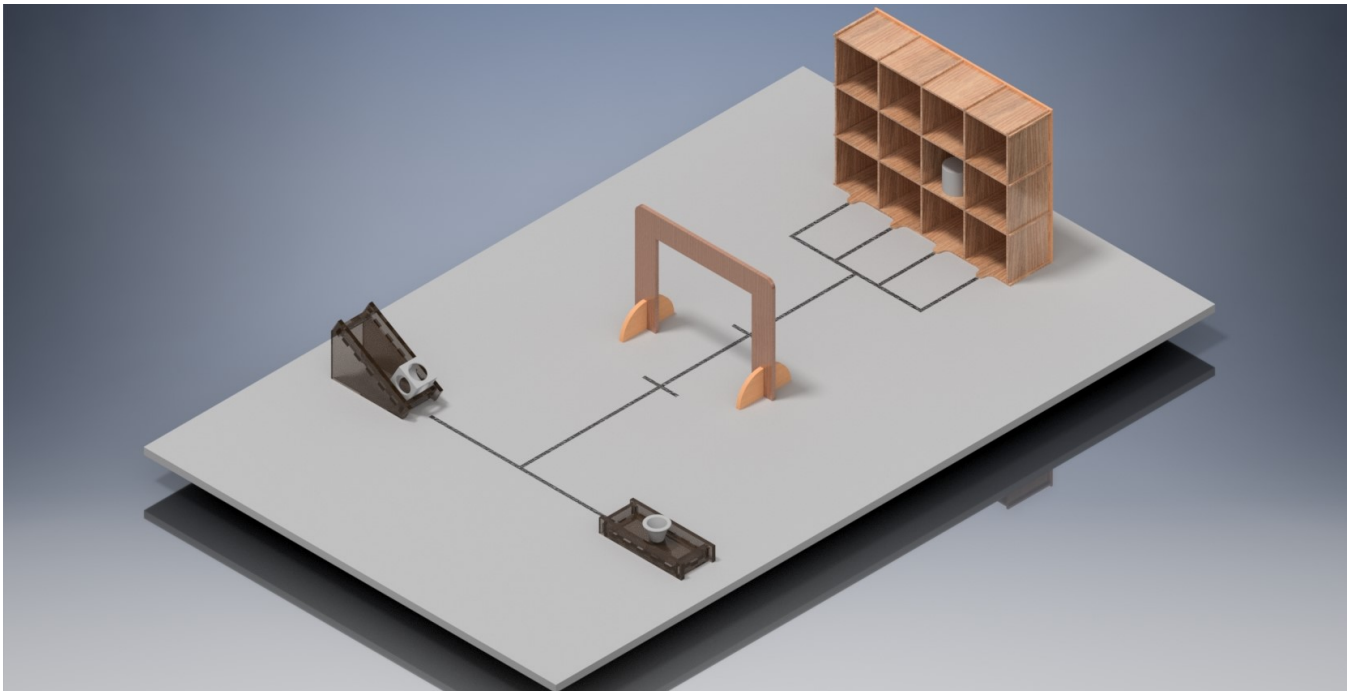
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GATE	Does the robot fit through the Gate? This does not count for field augmentations. (Yes(0)/ No (1))		0	-27.5	
	Final maximum score with field communications:				275
	Final maximum score without field communications:				235
	NOTE: Project graded out of 250 points				

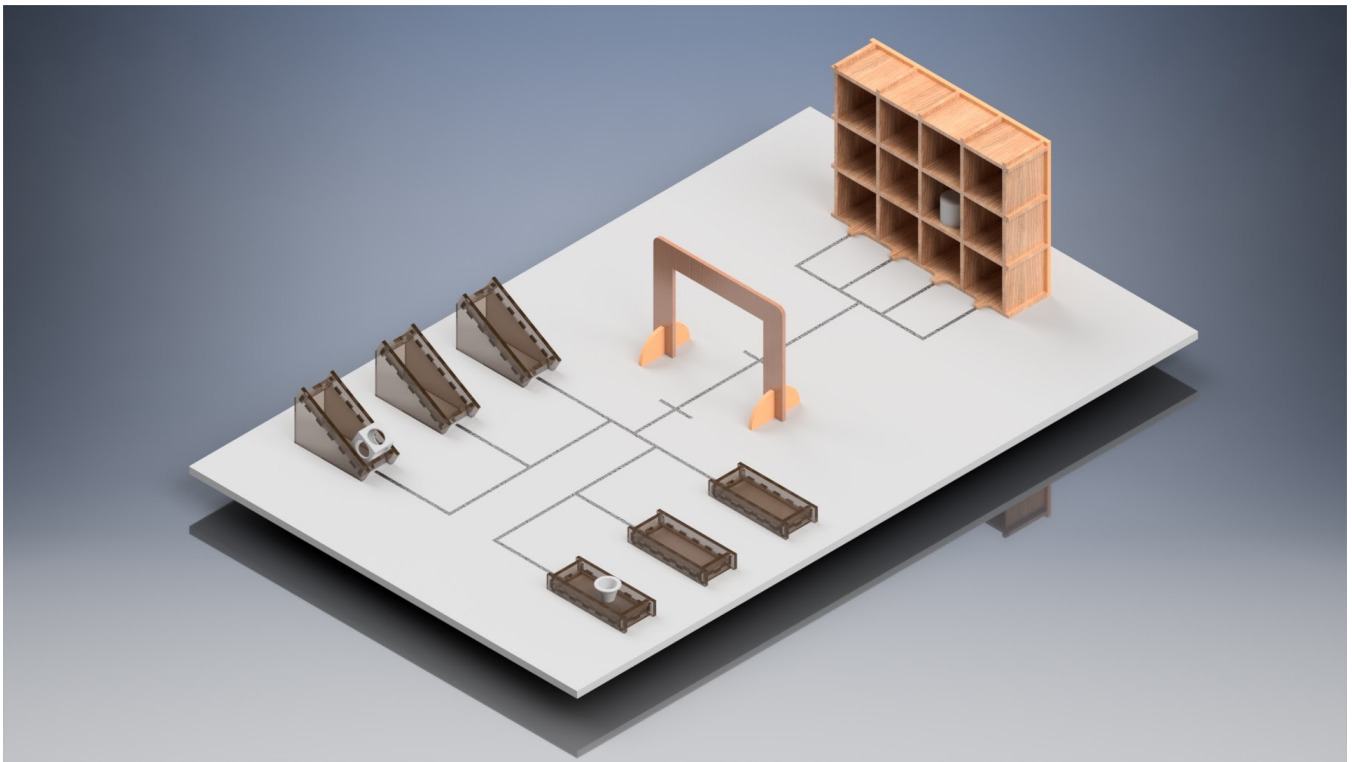
Appendix K: Supplemental Final Project Images



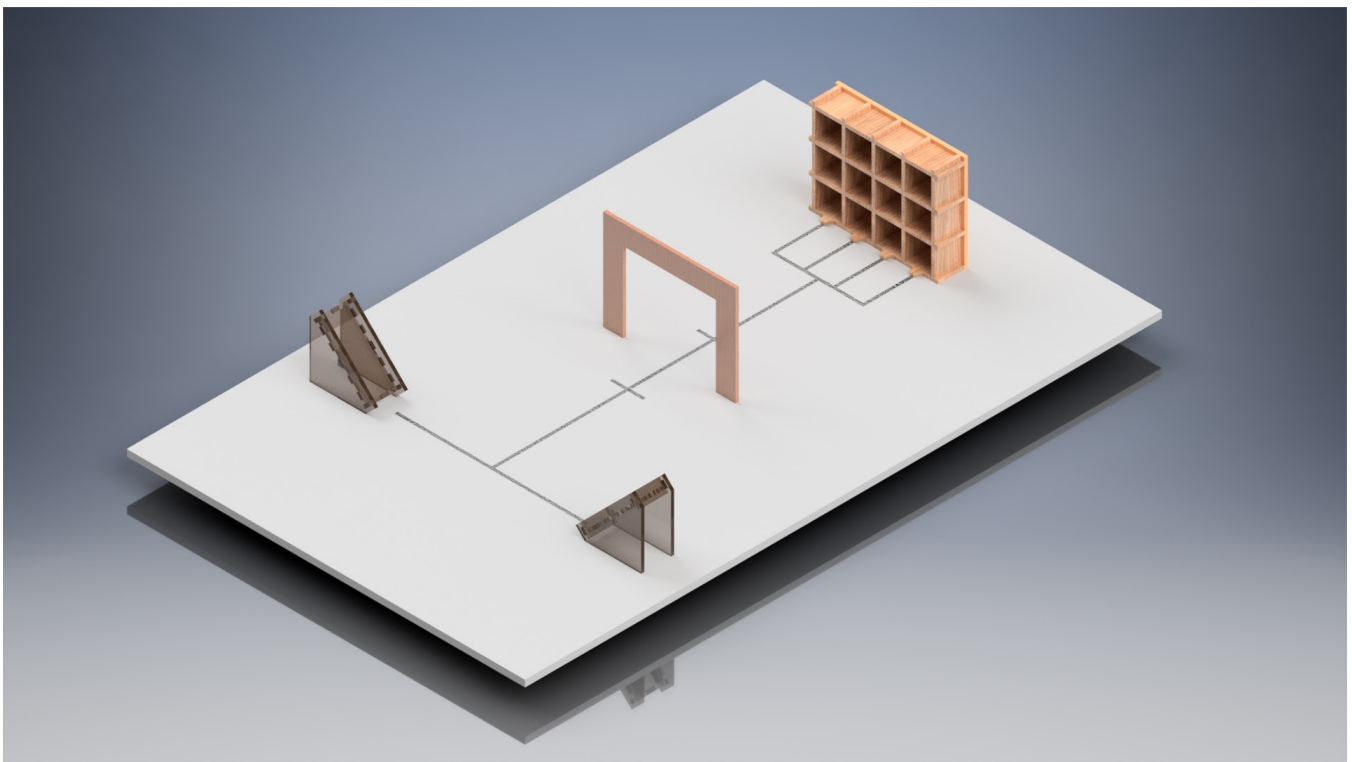
Appendix K, Figure 2: Possible Final Project Objects



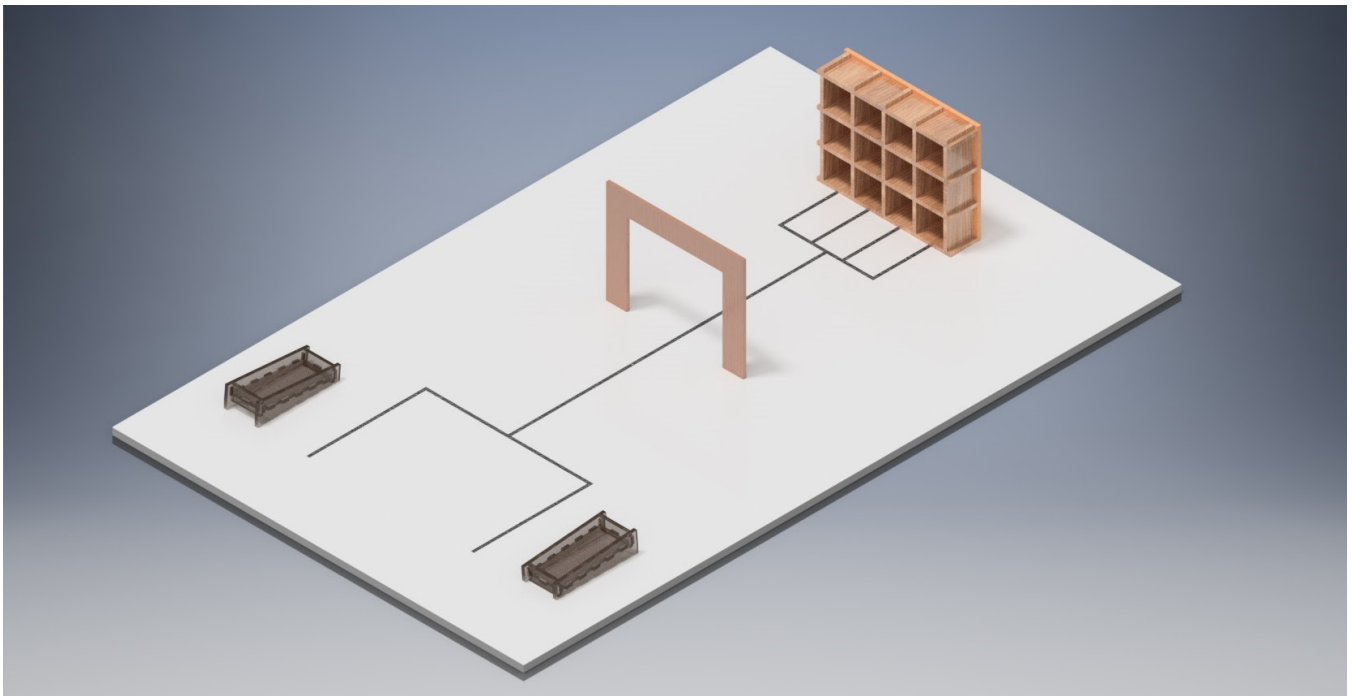
Appendix K, Figure 3: Final Project Field with a 30° Pick Up location and a flat Drop Off location



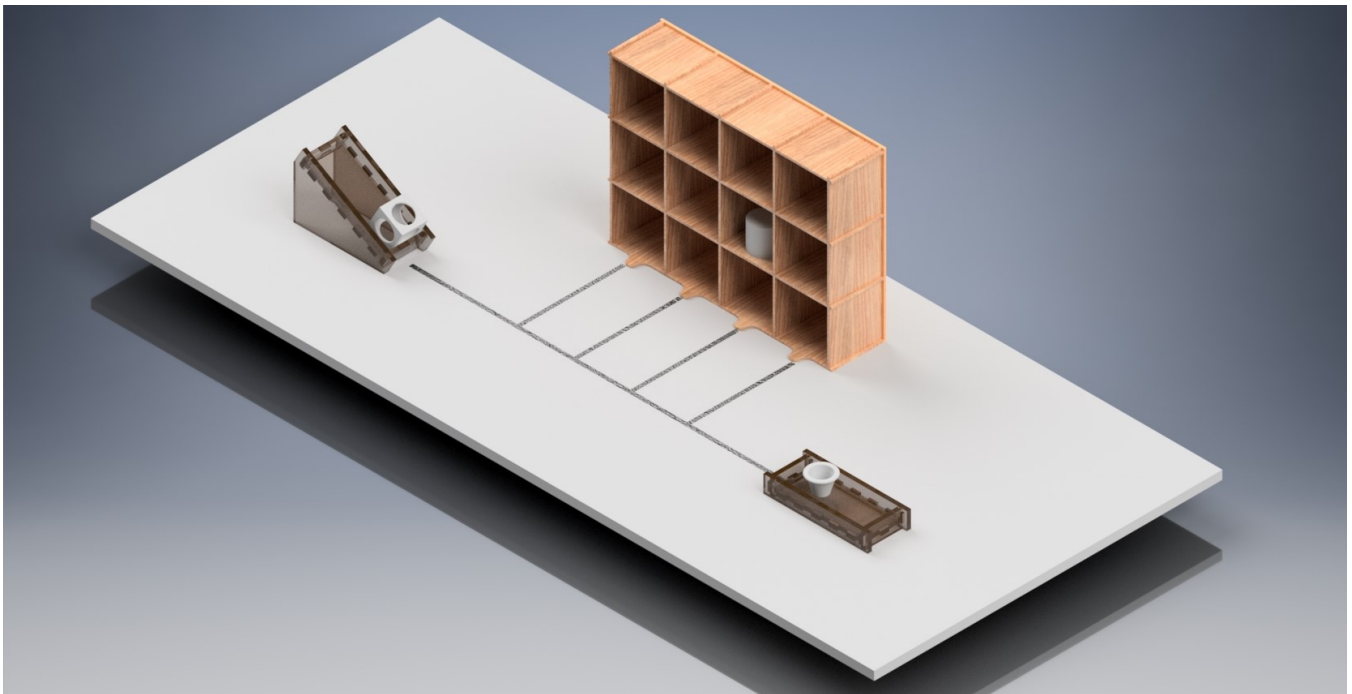
Appendix K, Figure 4: Final Project Field with three 30° Pick Up locations and three flat Drop Off locations



Appendix K, Figure 5: Final Project Field with a 45° Pick Up location and a 45° Drop Off location



Appendix K, Figure 6: Final Project Field with a 5° Pick Up location and a 5° Drop Off location



Appendix K, Figure 7: Final Project Field with simpler field layout

Appendix L: Lab Evaluation Table

Lab Evaluation

Sorted By Score

Lab	Aspect	Educational value	Final Project Relivance (1-5)	NEW Final Project Relivance (1-5)	time consuming?	Composite score	Reasoning
2	Using LabView in tandem with Arduino	2	1	1	20	-1	LabView is a useful engineering toolbox that is used in industry, for the purpose of this lab students are not required to know much about how the software works
3	Algodo	1	1	1	15	-0.75	Not engineering software. Redundant with other software/physical model
4	Design, build, and test an H-Bridge driver circuit for DC motor control	3	2	2	30	-0.5	Prototyping circuits is a valuable skill. Few teams use the H-bridge as their motor controller
Possible addition	Solenoids (electrical)	2	1	2	20	0	Actuation method
2	Mathcad waveforms	3	1	1	15	1.25	Mathcad is a useful computer program for solving mathematical problems, plotting waveforms is only a small aspect of what is capable of
Possible addition	Vacuum	2	1	2	15	1.25	Useful end effector knowledge
Possible addition	Stepper motors	3	1	4	25	1.75	Useful mechanism design knowledge
1	NPN Transistors and their limits	4	1	1	15	2.25	Important educationally. Too low level for need in final project.
4	Program a real-time-control system to generate PWM signals	3	2	1	15	2.25	New board will be much faster. Squeezing extra performance out of you PWM isn't as needed
Possible addition	Geartrain design with worm?	4	2	5	35	2.25	Useful mechanism design knowledge
Possible addition	Pneumatic cylinder force and control	4	1	4	25	2.75	Type of actuation method that does not recieve focus. Kevin apparently has them
Possible addition	Pulleys	4	1	3	20	3	Type of actuation method that does not recieve focus
2	Experimental motor analysis - torque/volt	3	1	3	15	3.25	Useful to help derive data sheets for motors for which there are none, most motor applications will have motor data sheets though
4	Wiring H-Bridge	3	2	2	15	3.25	Few teams use an H-Bridge but instead use vex motor controllers. Still has educational value in explaining how motor controllers work.
2	Experimental limitation testing of Arduino Mega 2560 (operation time depanyency)	4	3	2	20	4	Understanding limitations of hardware is essential to not making fatal design flaws
Possible addition	Brushless motors	3	1	4	15	4.25	Useful mechanism design knowledge
2	Experimental motor analysis - speed/voltage	3	1	3	10	4.5	Useful to help derive data sheets for motors for which there are none, most motor applications will have motor data sheets though
3	Creating PWM signals in various ways on the arduino	3	2	2	10	4.5	Theory behind different meathods of preforming the same action is useful to demonstrate the pros and cons of each; PWM is a very commonly used signal type
4	Matlab Simulink PID simulation of a physical model	5	3	3	25	4.75	Not directly applicable to final projects but helpful to understanding PID tuning.
Possible addition	Lead Screw torque and force calculations	4	1	4	15	5.25	Type of actuation method that does not recieve focus
Possible addition	MOSFETS (practical)	4	1	4	15	5.25	MOSFETS are useful ECE components for controlling the voltage in a circuit, currently recieve little focus
1	Relays	4	2	2	10	5.5	Useful physical system to compare with MOSFETs
2	Experimental motor analysis-stall and free current	3	1	3	6	5.5	Useful to help derive data sheets for motors for which there are none, most motor applications will have motor data sheets though
3	Use Bluetooth	4	5	1	15	6.25	New final project does not contain Bluetooth
Possible addition	Rack and Pinion	4	2	4	15	6.25	Type of actuation method that does not recieve focus
1	SolidWorks/CAD of Six-bar mechanism	5	5	5	30	7.5	Core robotics/mechanical engineering skill
1	MOSFETS (theory)	4	2	2	2	7.5	Important educationally. Too low level for need in final project.
2	Using a signal generator	4	3	3	10	7.5	Working knowlage of common bench tools is useful for the various applications that they are useful for
2	Using an oclliscop	4	3	3	10	7.5	Working knowlage of common bench tools is useful for the various applications that they are useful for
4	Use of included python program to help tune PID values	5	4	4	20	8	Use of other tools to aid in PID tuning will make tuning PID easier in the future
3	Experimental verification of position and velocity analysys	4	4	4	15	8.25	Verification of theory is important to help reinforce concepts
3	Building a slider-crank mechanism	3	5	4	15	8.25	Useful actuation mechanism, experiance building the structure will provide students with a hands on experiance with it provideing them insight into common mistakes
2	Building simple circuits	4	3	3	5	8.75	ECE is a major component of Robotics Engineering, and building simple circuits is a basic skill in ECE
1	Non-Grashof four-bar	5	4	4	15	9.25	Core actuation concept in robotics. Four-bars are slightly less important in new final project
1	Slider crank	4	4	5	15	9.25	Important option for final project manipulator. Not very intellectually challenging.
1	Building a simple mechanism	3	5	5	15	9.25	Core robotics/mechanical engineering concept
1	Position analysis for simple mechanisms	5	5	5	20	10	Core robotics/mechanical engineering concept
4	Advanced line following (state machine)	5	5	5	20	10	State machines are a core programming concept in robotics
1	Grashof four-bar linkage	5	5	4	15	10.25	Core actuation concept in robotics. Four-bars are slightly less important in new final project
2	ECE experiment design to verify theory	5	4	4	10	10.5	Being able to design circuits to verify theory before moving forward with implementation is important to prevent failures later in development
4	Implementation of experimental PID values on embedded controller	5	5	5	15	11.25	Programming PID is a core concept in robotics
3	Interrupts	5	5	5	10	12.5	Important concept in robotics and control of time dependent systems

Table 6 – Lab Evaluation Table Sorted By Score

Lab	Aspect	Educational value	Final Project Relevance (1-5)	NEW Final Project Relevance (1-5)	time consuming?	Composite score	Reasoning
1	Grashof four-bar linkage	5	5	4	15	10.25	Core actuation concept in robotics. Four-bars are slightly less important in new final project
1	Position analysis for simple mechanisms	5	5	5	20	10	Core robotics/mechanical engineering concept
1	Non-Grashof four-bar	5	4	4	15	9.5	Core actuation concept in robotics. Four-bars are slightly less important in new final project
1	Slider crank	4	4	5	15	9.25	Important option for final project manipulator. Not very intellectually challenging.
1	Building a simple mechanism	3	5	5	15	8.75	Core robotics/mechanical engineering concept
1	SolidWorks/CAD of Six-bar mechanism	5	5	5	30	7.5	Core robotics/mechanical engineering skill
1	MOSFETS (theory)	4	2	2	2	8	Important educationally. Too low level for need in final project.
1	Relays	4	2	2	10	6	Useful physical system to compare with MOSFETs
1	NPN Transistors and their limits	4	1	1	15	3	Important educationally. Too low level for need in final project.
2	ECE experiment design to verify theory	5	4	4	10	10.75	Being able to design circuits to verify theory before moving forward with implementation is important to prevent failures later in development
2	Building simple circuits	4	3	3	5	9	ECE is a major component of Robotics Engineering, and building simple circuits is a basic skill in ECE
2	Using a signal generator	4	3	3	10	7.75	Working knowledge of common bench tools is useful for the various applications that they are useful for
2	Using an oscilloscope	4	3	3	10	7.75	Working knowledge of common bench tools is useful for the various applications that they are useful for
2	Experimental motor analysis-stall and free current	3	1	3	6	6	Useful to help derive data sheets for motors for which there are none, most motor applications will have motor data sheets though
2	Experimental motor analysis - speed/voltage	3	1	3	10	5	Useful to help derive data sheets for motors for which there are none, most motor applications will have motor data sheets though
2	Experimental limitation testing of Arduino Mega 2560 (operation time dependency)	4	3	2	20	4.25	Understanding limitations of hardware is essential to not making fatal design flaws
2	Experimental motor analysis - torque/volt	3	1	3	15	3.75	Useful to help derive data sheets for motors for which there are none, most motor applications will have motor data sheets though
2	Mathcad waveforms	3	1	1	15	1.75	Mathcad is a useful computer program for solving mathematical problems, plotting waveforms is only a small aspect of what is capable of
2	Using LabView in tandem with Arduino	2	1	1	20	-0.75	LabView is a useful engineering toolbox that is used in industry, for the purpose of this lab students are not required to know much about how the software works
3	Interrupts	5	5	5	10	12.5	Important concept in robotics and control of time dependent systems
3	Experimental verification of position and velocity analysis	4	4	4	15	8.25	Verification of theory is important to help reinforce concepts
3	Building a slider-crank mechanism	3	5	4	15	7.75	Useful actuation mechanism, experience building the structure will provide students with a hands on experience with it providing them insight into common mistakes
3	Use Bluetooth	4	5	1	15	6	New final project does not contain Bluetooth
3	Creating PWM signals in various ways on the arduino	3	2	2	10	4.75	Theory behind different methods of performing the same action is useful to demonstrate the pros and cons of each; PWM is a very commonly used signal type
3	Algodoo	1	1	1	15	-0.75	Not engineering software. Redundant with other software/physical model
4	Implementation of experimental PID values on embedded controller	5	5	5	15	11.25	Programming PID is a core concept in robotics
4	Advanced line following (state machine)	5	5	5	20	10	State machines are a core programming concept in robotics
4	Use of included python program to help tune PID values	5	4	4	20	8.25	Use of other tools to aid in PID tuning will make tuning PID easier in the future
4	Matlab Simulink PID simulation of a physical model	5	3	3	25	5.25	Not directly applicable to final projects but helpful to understanding PID tuning.
4	Wiring H-Bridge	3	2	2	15	3.5	Few teams use an H-Bridge but instead use vex motor controllers. Still has educational value in explaining how motor controllers work.
4	Program a real-time-control system to generate PWM signals	3	2	1	15	2.5	New board will be much faster. Squeezing extra performance out of you PWM isn't as needed
4	Design, build, and test an H-Bridge driver circuit for DC motor control	3	2	2	30	-0.25	Prototyping circuits is a valuable skill. Few teams use the H-bridge as their motor controller
Possible addition	Rack and Pinion	4	2	4	15	6.75	Type of actuation method that does not receive focus
Possible addition	Lead Screw torque and force calculations	4	1	4	15	6	Type of actuation method that does not receive focus
Possible addition	MOSFETS (practical)	4	1	4	15	8	MOSFETS are useful ECE components for controlling the voltage in a circuit, currently receive little focus
Possible addition	Brushless motors	3	1	4	15	4.75	Useful mechanism design knowledge
Possible addition	Pulleys	4	1	3	20	3.75	Type of actuation method that does not receive focus
Possible addition	Pneumatic cylinder force and control	4	1	4	25	3.5	Type of actuation method that does not receive focus, Kevin apparently has them
Possible addition	Gear Train design with worm?	4	2	5	35	2.75	Useful mechanism design knowledge
Possible addition	Stepper motors	3	1	4	25	2.25	Useful mechanism design knowledge
Possible addition	Vacuum	2	1	2	15	1.5	Useful end effector knowledge
Possible addition	Solenoids (electrical)	2	1	2	20	0.25	Actuation method

Table 7 – Lab Evaluation Table Sorted By Lab

