

AC 2010-372: ROBOTICS ENGINEERING: ASSESSING AN INTERDISCIPLINARY PROGRAM

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Robotics Engineering: Assessing an Interdisciplinary Program

Abstract

In the spring of 2007, Worcester Polytechnic Institute introduced a BS degree program in Robotics Engineering. The degree program is a collaborative effort, involving faculty from the departments of computer science, electrical and computer engineering and mechanical engineering. The motivation for the program is twofold: First of all, the dramatic drop in the cost of sensors, computers and actuators is making possible entirely new classes of products, capable of both automating nontrivial tasks as well as performing functions not possible before. Secondly, robotics has proven to be an excellent means to excite pre-college students about science, technology, and engineering. While much of the technical foundation for the new program is drawn from Computer Science, Electrical, and Mechanical Engineering, we believe that Robotics Engineering is on the path to emerging as an independent discipline with its own intellectual goals and body of knowledge. Thus, graduates from the program are expected to exhibit mastery that is greater than simply knowing some computer science, electrical and mechanical engineering. Assessment of student learning therefore must go beyond measuring the mastery of the various knowledge domains contributing to the discipline. Here we discuss our current assessment results, the tools we have used, and our plans for continuing assessment.

There are three measures of success for any new program:

1. The number and quality of students attracted to the program,
2. The extent to which graduates are employed or admitted to graduate school, and
3. The degree to which the program achieves its educational objectives.

The first measure, enrollment, is, *sine qua non*, the most important and straightforward. This has already been answered in the affirmative. Students have flocked to the program, already enrolling almost as many students per class as Computer Science and Electrical and Computer Engineering. The second measure, graduate success, is difficult to assess definitively at this early stage as only a few students have graduated yet (those who transferred into the program as it was introduced. As the large cohorts of students who have been RBE majors for most of their stay at WPI graduate, assessing how well the program has succeeded in building a new interdisciplinary program that is more than the “sum of its parts” remains a challenge. The third measure, program assessment, is well underway. The core of the program is contained in five new courses, an introductory course and four Unified Robotics Engineering courses. We have gathered extensive formal and informal input from these courses and while the overall student satisfaction has been high, the feedback has unearthed issues involving expected workload and integration. These have lead to several modifications in the courses. In addition to the unified courses, students take several courses already offered, from the three departments’ collaboration on the program as well as others. The feedback has shown a few cases where the required background has not been optimal for subsequent courses and the program requirements have been modified to address this feedback.

1. Introduction

In the spring of 2007, Worcester Polytechnic Institute (WPI) introduced a BS degree program in Robotics Engineering (RBE)⁸. The RBE degree program is a collaborative effort, involving faculty from the departments of computer science, electrical and computer engineering and mechanical engineering. The motivation for the program is twofold: First of all, the dramatic drop in the cost of sensors, computers and actuators is making possible entirely new classes of products, capable of both automating nontrivial tasks as well as performing functions not possible before. Secondly, robotics has proven to be an excellent means to excite pre-college students about science, technology, and engineering. While much of the technical foundation for the new program is drawn from Computer Science, Electrical, and Mechanical Engineering, we believe that Robotics Engineering is on the path to emerging as an independent discipline with its own intellectual goals and body of knowledge. Thus, graduates from the program are expected to exhibit mastery that is greater than simply knowing some computer science, electrical and mechanical engineering. Assessment of student learning therefore must go beyond measuring the mastery of the various knowledge domains contributing to the discipline.

1.1. Program Overview

The RBE degree program was designed top-down, starting with program objectives and outcomes. Recognizing that it is impossible to include a comprehensive course of study equivalent to a B.S. in CS, ECE, and ME in a 4-year degree, the RBE program provides a solid foundation in each, with applications drawn from Robotics. In keeping with WPI's educational approach, the curriculum engages students early and often in creative hands-on projects.

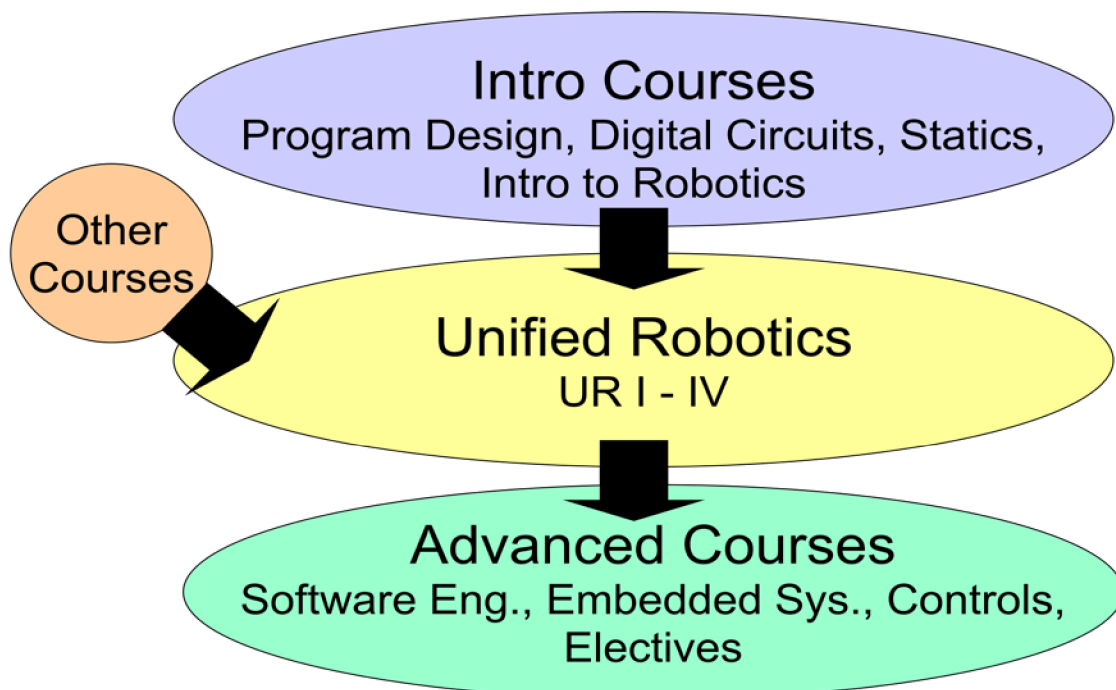


Figure 1. Curriculum organization.

As shown in Figure 1, the curriculum leverages introductory courses in CS, ECE, and ME, and Robotics, so that students understand the basics of engineering early on. Students also take an entry-level course in robotics to obtain an overview of the field. This is followed by the core of

the program: four Unified Robotics courses based on a “spiral curriculum” philosophy where the students are engaged in increasingly complex designs and various technical topics are introduced as needed. Each of these courses includes elements of CS, ECE and ME. To add cohesion within courses, each course in the unified sequence has its own focus, such as locomotion, sensing, manipulation, and navigation. Students in the Robotics program also take other required and elective courses, selected from courses already offered by the various engineering departments. In addition, the program includes a component in social issues and another in entrepreneurship to prepare future “entrepreneurial engineers”⁷. Like all majors at WPI, the program culminates in a capstone design experience wherein students synthesize their accumulated knowledge in a major project. There are many paths through the curriculum; select illustrative samples are shown in ⁹.

1.2. Context

Assessment is an integral part of the accreditation process⁶. As an emerging engineering discipline^{3,4}, Robotics Engineering falls naturally under the purview of the ABET Engineering Accreditation Commission. However, Robotics Engineering is not recognized by ABET as a distinct engineering discipline, hence there are no program-specific criteria to follow for accreditation. Nonetheless, we have planned the program as if it were accreditable, based on program objectives and outcomes, and with mathematics, science, and engineering and design components consistent with general criteria for accreditation. Such a program is potentially accreditable by ABET/EAC under General Engineering, which has no program-specific criteria. We are currently in the process of applying for accreditation during the 2010-2011 accreditation cycle. A positive outcome would strongly reinforce the success of the program in achieving its goals, objectives, and outcomes, contributing another kind of program assessment in addition to those listed below.

The ABET Engineering Accreditation Commission defines general criteria that all accreditable engineering programs must satisfy¹. The general criteria require program educational outcomes and objectives. The professional component must include one year of math and science and one and one-half years of engineering topics, plus a general education component. In this paper, we concern ourselves primarily with the engineering component, although other areas manifest themselves as well.

2. Measures of Success

There are three measures of success for any new program:

1. The number and quality of students attracted to the program,
2. The extent to which graduates are employed or admitted to graduate school, and
3. The degree to which the program achieves its educational objectives.

The first measure, enrollment, is, *sine qua non*, the most important and straightforward. This has already been answered in the affirmative. Students have flocked to the program, with the number of first-year students going from 0 in 2006-07 to 59 in 2007-08 to 68 in 2008-09, making RBE the fifth most popular major among incoming students at WPI. RBE already enrolls almost as many students per class as Computer Science and Electrical and Computer Engineering.

The second measure, graduate success, is difficult to assess definitively at this early stage as only a few students have graduated yet (those who transferred into the program as it was introduced). However, at this writing, among the handful of graduates all have jobs in the profession or are in graduate school. As the large cohorts of students who have been RBE majors for most of their stay at WPI graduate, it will be possible to get a better sense of their professional success.

The third measure, program assessment, is well underway, as discussed in the next section.

3. Assessment Process

The assessment process is motivated top-down in an effort to improve upon the program's success in meeting its objectives. The goal is to continuously improve the quality of education while keeping the overall curriculum on trajectory.

3.1. Continuous Improvement Process

The continuous improvement process forms feedback loops that include objectives, faculty, courses and projects, students, and student work as shown in the figures below.

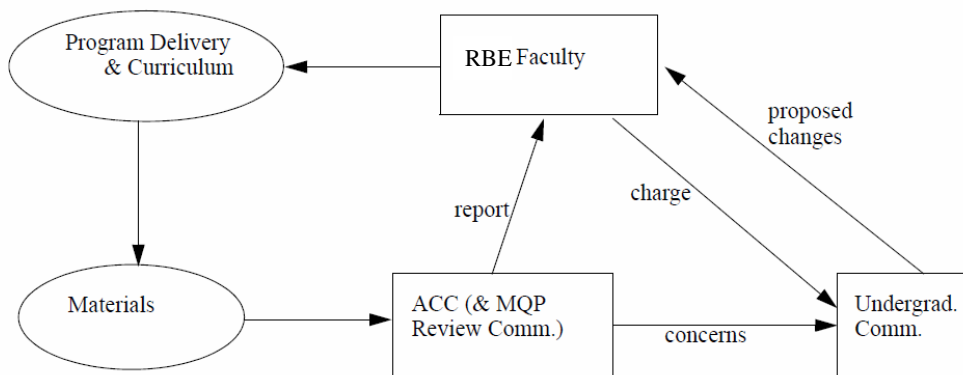


Figure 2. Curricular revision flow.

The Accreditation Coordinating Committee (ACC) has primary responsibility for reporting to the RBE Faculty. Senior Capstone projects (MQPs) are reviewed by every program every two years and those results are likewise reported.

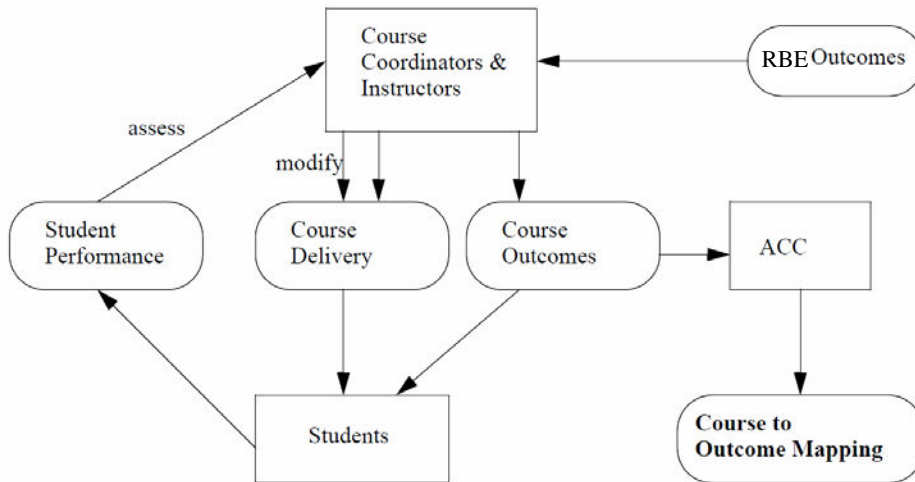


Figure 3. Continuous improvement process flow.

All assessment is performed relative to overall program objectives and specific educational outcomes.

3.2. Objectives

The objectives of the Robotics Engineering Program are to educate men and women to

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

3.3. Measurable Outcomes

Based on the above objectives, the outcomes are that all 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.

These outcomes correspond to ABET/EAC outcomes (a) through (k).

3.4. Assessment Instruments

Based on the Objectives and Outcomes the RBE program faculty uses a variety of methods of measurement to collect data. We analyze, evaluate, present, discuss, and try to make adjustments that reduce perceived weaknesses while maintaining perceived strengths. Some methods generate little analyzable data, but instead provide an opportunity for reflection about the state of the program.

We can divide the assessment instruments into several categories. WPI places great emphasis on undergraduate projects, including a junior-level project on the *Interaction of Science, Technology, and Society* (the Interactive Qualifying Project or IQP) and a senior-level project in one's major field of study (the Major Qualifying Project or MQP). Both types of Qualifying Project are generally performed in teams, include written reports and oral presentations, and are equivalent to one-quarter year of effort.

- **IQP Review Report:** At regular intervals (usually yearly) determined by the university administration, a university-wide evaluation is performed on a large sample of completed IQPs.
- **MQP Review Report:** At regular intervals determined by the university administration, all programs undertake a significant review of the content and quality of that year's MQPs. Many of the outcomes are assessed, as well as the correlation between perceived quality and grade assigned.
- **MQP Presentation Evaluations:** In April every year all graduating students present their MQPs to their departments and the public. The RBE faculty evaluates every presentation using a standard form. The resulting data are mostly used to evaluate presentation skills.
- **Advisor's Evaluation of MQP:** Every MQP has a faculty advisor who provides an evaluation of every completed MQP. The resulting data are used to provide a view of how well MQPs are supporting outcomes.

There are also more traditional assessment instruments that relate individual courses to desired outcomes.

- **Student evaluations of courses:** At the end of every term students evaluate the course and instructor for every course in which they are registered. Faculty members receive an electronic report of their evaluation. The department head also gets information about every evaluation. This allows teaching quality, as it varies across instructors and courses, to be monitored.

- **Course to Outcomes mapping:** Every course should have a mapping of intended educational outcomes for the course to the program's outcomes, associated with the methods for measuring whether that outcome was achieved—typically projects, exams, portfolios, etc. This mapping is often included in the web pages for the course.
- **Course Enrollments:** Course enrollments are monitored regularly to ensure that enough sections of courses are offered so that majors can graduate on time.

Some instruments measure the overall educational experience of students.

- **Transcripts of Seniors:** Transcripts of students applying for graduation are checked by the Registrar's Office using software that ensures that all program requirements have been met. In addition, student records are reviewed by a faculty member to indicate specific problems to the student or to indicate approval. This ensures that all graduating students meet university and the program course distribution requirements.
- **NSSE:** The National Survey of Student Engagement⁵ is a survey of how students indicate they use their time for various kinds of academic and non-academic activities. The designers of NSSE argue that students who spend more time on educationally-beneficial activities are more likely to learn effectively.
- **EBI:** Seniors graduating in engineering complete the EBI (Educational Benchmarking, Inc.) surveys². We use these results to identify areas where our graduating seniors indicate their overall academic experience has been less positive than those reported by seniors at similar universities. Fortunately, seniors have reported consistently strongly positive responses in almost all areas of the EBI survey.
- **CDC Report:** The Career Development Center provides an annual report summarizing internships, post-graduation employment, and attendance at graduate school.

Other forms of feedback are internal to the program.

- **Advisory Board Report:** Bi-annual RBE Advisory Board meetings provide feedback to the program director, and offer suggestions about improvements and future directions.
- **Faculty Retreats:** The program conducts a yearly faculty retreat with the goals of reviewing recent self-assessment data, evaluating current strengths and weaknesses, and proposing solutions to problems. Typically the list of action items is addressed during the following year(s).
- **Faculty meetings:** The RBE faculty meets as a group every week during the academic year. A variety of issues are discussed, including research, ongoing and planned activities, staffing, new courses, and changes to regulations.
- **Faculty Evaluations:** Every year each faculty member prepares an activity report about research, teaching and service for that year and delivers it to his/her Department Head, and subsequently the Provost, for their evaluation. The Department Head provides an evaluation of the faculty member, and discusses strengths, weaknesses and plans with them.

4. Assessment Results

With only 4 graduates to date, it is hard to draw meaningful conclusions about senior projects and from alumni. However, course-based assessments are informative, as shown in Figures 4 and 5. Student course evaluations include over 30 questions. Here we focus on three of the more important questions: My overall rating of the quality of this course is ..., The instructor's organization of the course was ..., and The amount I learned from the course was Responses range from 1 (lowest) to 5 (highest). Figure 4 shows results for RBE 2001 Unified Robotics I; Figure 5 shows results for RBE 2002 Unified Robotics II. These courses are selected because they form part of the core robotics curriculum, and because they have each been offered three times, permitting some trends to be discerned. We note, however, that various faculty members have taught these courses, making it difficult to separate differences in instructors from course evolution. RBE 3001 Unified Robotics III and RBE 3002 Unified Robotics IV have each been taught once each, hence are not included in this analysis.

Additional assessment data appears in Appendix A.

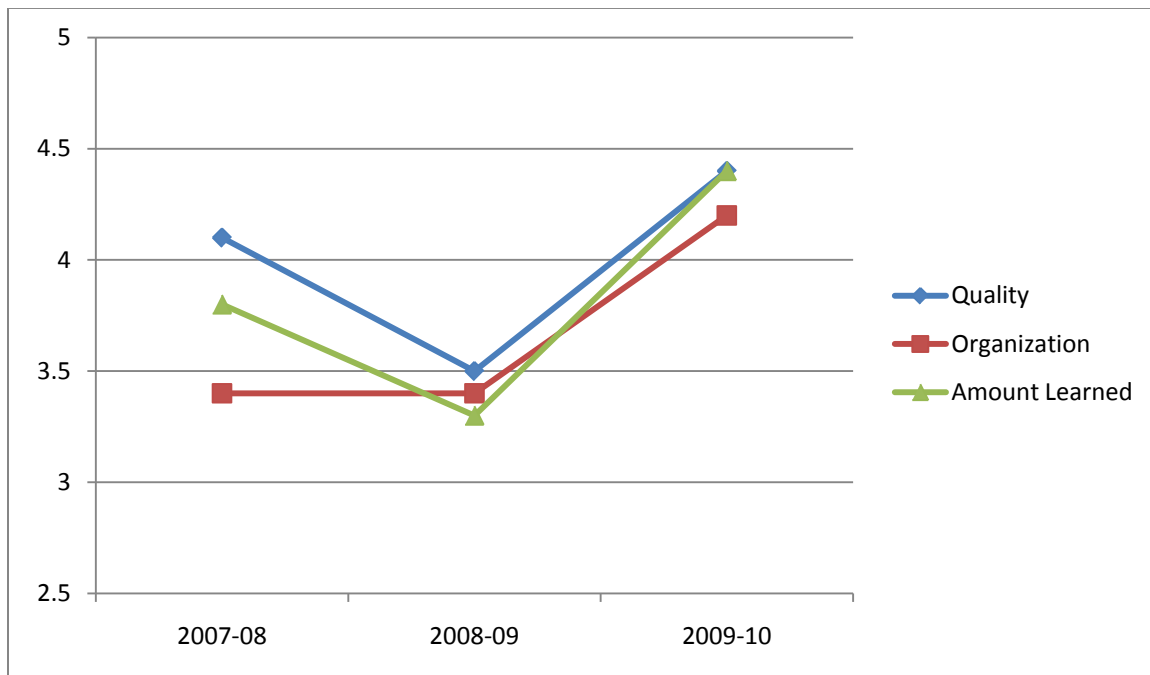


Figure 4. Selected student course evaluation for RBE 2001 Unified Robotics I.

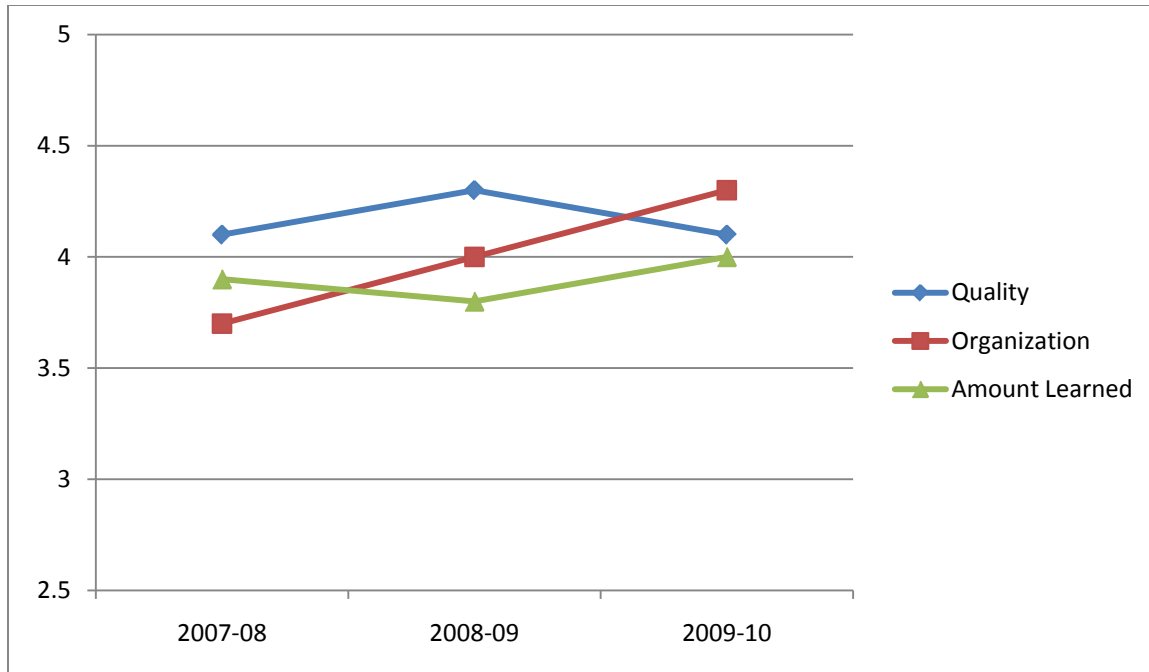


Figure 5. Selected student course evaluation for RBE 2002 Unified Robotics II.

5. Conclusions

We have gathered extensive formal and informal input from these courses and while the overall student satisfaction has been high, the feedback has unearthed issues involving expected workload and integration. These have led to several modifications in the courses and an observable increase in student perception of quality. In addition to the unified courses, students take several courses already offered, from the three departments' collaboration on the program as well as others. The feedback has shown a few cases where the required background has not been optimal for subsequent courses. We have revised the program requirements to address this feedback, for example, by adding a requirement for Linear Algebra and removing a requirement for Discrete Mathematics.

Perhaps most importantly, the various assessments and feedback mechanisms have shown that as more students go through the program, increasingly the students are viewing the program as a unified discipline. Initially there was a tendency among both students and faculty to refer to the “mechanical” or “electrical” part of the curriculum but as better and better integration is achieved, students are starting to view programming, circuits and kinematics simply as what they need to know as Robotics Engineers.

6. Acknowledgements

The authors wish to thank the Robotics Engineering faculty at WPI who have worked hard to make the vision of robotics education become reality, and Ms. Pamela St. Louis for coordinating the RBE program's assessment activities. In addition, we thank the anonymous reviewers for their constructive comments that have improved the presentation of the paper.

A. Appendix

An important component of the assessment process is the individual course evaluations. Students are surveyed at the completion of each course and data are compiled for the courses in the core curriculum. The data are reviewed by the RBE faculty during the Annual Retreat. As a result, each course in the Unified Robotics sequence has gone through revisions at least once based on this review process. The table below presents sample data collected from the student course evaluations.

| |
|---|
| <p><i>RBE 2001 Unified Robotics I (A-term 2008)</i></p> <ul style="list-style-type: none">• 54 responses• 88% rated the instructors as very good or excellent.• 68% said that they learned more from the course relative to other courses.• 74% found the organization of the course very good or excellent.• 68% ranked the educational value of the assigned work as very good or excellent.• 87% said that they put more effort into the course relative to other courses.• 64% reported that they spent 17 hours or more per week on all activities related to the course. 88% reported 13 hours or more. |
| <p><i>RBE 2002 Unified Robotics II (B-term 2008)</i></p> <ul style="list-style-type: none">• 45 responses• 86% rated the instructors as very good or excellent.• 86% said that they learned more from the course relative to other courses.• 91% found the organization of the course very good or excellent.• 79% ranked the educational value of the assigned work as very good or excellent.• 91% said that they put more effort into the course relative to other courses.• 51% reported that they spent 17 hours or more per week on all activities related to the course. 84% reported 13 hours or more. |
| <p><i>RBE 3001 Unified Robotics III (C-term 2009)</i></p> <ul style="list-style-type: none">• 21 responses• 90% rated the instructors as very good or excellent.• 82% said that they learned more from the course relative to other courses.• 73% found the organization of the course very good or excellent.• 83% ranked the educational value of the assigned work as very good or excellent.• 100% said that they put more effort into the course relative to other courses.• 100% reported that they spent 21 hours or more per week on all activities related to the course. |
| <p><i>RBE 3002 Unified Robotics IV (D-term 2009)</i></p> <ul style="list-style-type: none">• 28 responses• 71% rated the instructors as very good or excellent.• 72% said that they learned more from the course relative to other courses.• 37% found the organization of the course very good or excellent.• 71% ranked the educational value of the assigned work as very good or excellent.• 88% said that they put more effort into the course relative to other courses.• 64% reported that they spent 17 hours or more per week on all activities related to the course. |

96% reported 13 hours or more.

RBE 2001 Unified Robotics I (A-term 2009)

- 30 responses
- 86% rated the instructors as very good or excellent.
- 80% said that they learned more from the course relative to other courses.
- 83% found the organization of the course very good or excellent.
- 80% ranked the educational value of the assigned work as very good or excellent.
- 86% said that they put more effort into the course relative to other courses.
- 43% reported that they spent 17 hours or more per week on all activities related to the course.
- 82% reported 13 hours or more.

RBE 2002 Unified Robotics II (B-term 2009)

- 33 responses
- 100% rated the instructors as very good or excellent.
- 72% said that they learned more from the course relative to other courses.
- 91% found the organization of the course very good or excellent.
- 81% ranked the educational value of the assigned work as very good or excellent.
- 74% said that they put more effort into the course relative to other courses.
- 43% reported that they spent 17 hours or more per week on all activities related to the course.
- 62% reported 13 hours or more.

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