IMPLEMENTATION OF AN UNDERGRADUATE ROBOTICS ENGINEERING CURRICULUM

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Abstract

This paper discusses the implementation of the B.S. degree in Robotics Engineering offered at the Worcester Polytechnic Institute (WPI). Robotics is fundamentally multi-disciplinary, drawing on Electrical Engineering, Mechanical Engineering, Computer Science and many other academic disciplines. While many programs include robotics as an element within a discipline such as Electrical Engineering, Mechanical Engineering or Computer Science, the Robotics Engineering Program at WPI took a decidedly different approach by introducing robotics as a new engineering discipline.

Introduction

As the robotics community celebrates "50 years of robotics" [1], there is no doubt that research and development in the field has evolved drastically since the introduction of the first industrial automation robot, the Unimate. With the advances in enabling technologies (electronics, hardware and computation) and components (sensors and actuators), intelligent vehicles have become capable of assisting human drivers in urban environments, vacuum cleaning and lawn mowing. Robots are becoming a common household appliance, and medical and rehabilitation robots are assisting with elder care.

It is now well-known that robotics has become a passion among students of all ages [2]. Robotics provides a new opportunity to capture the interests of students in grades K-12 and to introduce them to engineering and science. Currently, students are exposed as early as K-12 to a growing number of robot competitions such as the FIRST Robotics Competition (http://www.usfirst.org). Strong ties between these competitions, student enthusiasm, research, and education have been observed [3].

In response to this growing interest among K-12 students, institutions of higher education have been introducing robotics courses into their existing curricula [4-6]. The interdisciplinary nature of the field of robotics makes it suitable for incorporating robotics-focused engineering courses into engineering programs in one form or another with electrical and computer engineering, mechanical engineering and computer science programs being perhaps the most common places to find these courses. Indeed, it is very common to find robotics related modules and projects in undergraduate courses on embedded systems, analog electronics, dynamics, algorithms, as well as introductions to engineering. Moreover, robotics projects are frequently encountered in capstone design courses.

On the other end of the spectrum, there are many market forecasts predicting a significant increase in the deployment of robotic systems in the next decade. Much of the increase of the robotics volume is expected to be in emergency search and rescue, in health and elderly-care, in the leisure and entertainment market and in the defense industry [7]. It is projected that the leisure and entertainment robotics installations will increase by over 3 times in only 3 years (2008-2011). Gecko Systems International Corp. projects the growth of the elder-care robot market to reach $83 Billion in 2014. In Massachusetts alone, there are 75 robotics companies with more than 2500 employees and robot sales totaling $1 Billion according to a survey administered in May 2008 [8]. The growth expectations in robotics applications can also be gauged from research spending. According to a recent report, the rest of the world led by Japan, Korea, and the European Union, has recognized the irrefutable need to advance robotics technology and have made research investment commitments totaling over $1 billion [9].

Worcester Polytechnic Institute (WPI) introduced a BS degree program in Robotics Engineering (RBE) in the Spring of 2007. The motivation for establishing the program was two-fold. First, it is evident that robotics - the combination of sensing, computation and actuation in the physical world - is on the verge of rapid growth due to the dramatic reduction in cost and increasing availability of sensors, computing devices and actuators, and that the rapidly increasing needs in areas such as national defense and security, elder care, automation of household tasks, customized manufacturing, and interactive entertainment, will strongly drive the demand for engineers skilled in robotics. Second, it seems clear that robotics has already "caught on" with the current generation of high school students. Furthermore, robotics as an engineering discipline is an interdisciplinary field of study which can be used to enrich and broaden engineering education; it promotes teamwork, technical competency, innovation and lifelong learning; more importantly, it proved to be an effective tool for improving the recruitment and retention of a diverse range of students [2, 10]. As such, Robotics Engineering is an excellent fit for the undergraduate engineering education of 2020 described in the NAE report titled Educating The Engineer Of 2020 [11].

To the best knowledge of the authors, WPI is the only university in the U.S. that offers an undergraduate degree in robotics, although many offer minors (e.g., CMU, Rose-Hulman, Johns Hopkins in development), concentrations (e.g., Olin College, Michigan, RPI at the MS level, RIT, UC Santa Clara), focus areas (e.g. Arizona State University), and threads (e.g. Georgia Tech). A well-known robotics program is "Robotics Across the Curriculum" [12], which uses robotics in a set of five classes. However, the prime motivation is to use robotics to teach Computer Science, not robotics per se, although the final course in the sequence does focus on robotics. Another innovative program is Santa Clara University's Robotics Systems Laboratory [13], which has shown how student performance can be enhanced by robotics. Graduate degrees in robotics are offered by several universities (e.g., CMU, Michigan, U. Penn, Georgia Tech, South Dakota School of Mines, and WPI).

This paper discusses the implementation of the B.S. degree in Robotics Engineering offered at WPI. Robotics is fundamentally multi-disciplinary, drawing on Electrical Engineering, Mechanical Engineering, Computer Science and many other academic disciplines. While many programs include robotics as an element within a discipline such as Electrical Engineering, Mechanical Engineering or Computer Science, the Robotics Engineering Program at WPI took a decidedly different approach.

Specifically, rather than looking at robotics as an element within a larger engineering discipline, we have viewed robotics as an emerging engineering discipline unto itself, one which draws from other engineering disciplines but which, as in other disciplines, has an independent philosophy which underlies the application of technology to the solution of problems. Just as Electrical, Mechanical, and Software Engineers use their respective disciplinary paradigms, concepts, and tools to solve their respective problems, so too we envision that Robotics Engineers will use robotics systems paradigms, concepts, and tools to solve robotics problems. In other words, the philosophy which underlies Robotics Engineering is not merely the assemblage of a collection of electrical, mechanical and computer subsystems, but rather is the seamless integration of the appropriate robotic technologies into a feasible solution to a robotic problem. Further, while some design and analysis concepts are common to all engineering fields, different fields will employ unique approaches that are particularly suited to or require special emphasis within a specific discipline.

To gain depth of knowledge in fundamental engineering concepts, the academic program for students in Robotics Engineering includes selected courses in Electrical Engineering, Mechanical Engineering, Computer Science, Mathematics, Physics and other topics. However, to remain true to the underlying principles of the program, these courses are not the centerpieces of Robotics Engineering. Rather, there is a series of courses specifically in Robotics Engineering that seamlessly integrate electrical, mechanical and computer concepts in the context of building robotic systems.

RBE Curriculum Structure

Growth in the field of robotics, and a perceived need for engineers trained with multidisciplinary skills led the Worcester Polytechnic Institute (WPI) to create a new undergraduate degree program in Robotics Engineering (RBE) in the spring of 2007 [14]. As of the fall semester of 2009, the program has grown rapidly to become the fourth most popular major among incoming students at the institution, trailing only Mechanical Engineering, Electrical & Computer Engineering and Computer Science. The B.S. program produced its first graduates in May 2009 and it is seeking ABET-EAC accreditation under general engineering criteria in the 2010-2011 academic year.

The RBE program objectives 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 abstract concepts and practical skills from the separate engineering disciplines together 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.

The program has a structure that integrates the foundational concepts from computer science, electrical and computer engineering and mechanical engineering to introduce students to the multidisciplinary theory and practice of robotics engineering. For this purpose, a series of undergraduate courses were created consisting of Introduction to Robotics at the 1000 level (1st year) and a four-course Unified Robotics sequence at the 2000 and 3000 levels (sophomore and junior years, respectively). Figure 1 provides a visualization of the RBE curriculum. All courses are offered in 7-week terms with 4 hours of lecture and 2 hours of laboratory session per week. Further, in keeping with the long history of the WPI Plan [15], these courses emphasize project-based learning, hands-on assignments, and students' commitment to learning outside the classroom.

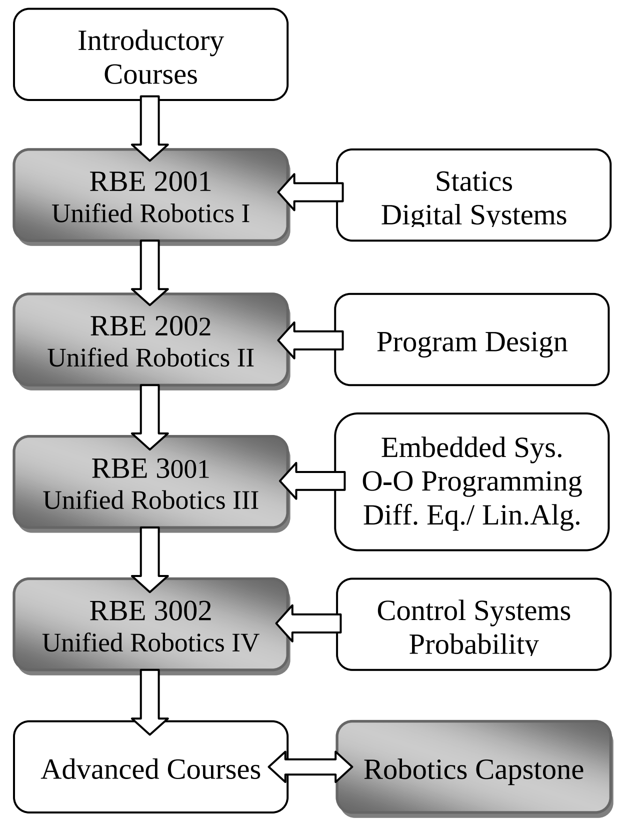

Figure 1: WPI's undergraduate Robotics Engineering curriculum is structured around four core courses called Unified Robotics I-IV.

It should be noted that while course RBE 1001 Introduction to Robotics is optional, it is expected that the Unified Robots I-IV courses will be taken in sequence by all Robotics Engineering students. It is essential that all Robotics Engineering majors complete all four core courses before beginning a Capstone Design project in their 4^{th} year.

As illustrated in Figure 1, the Unified Robotics sequence is supported by a number of traditional courses from computer science, electrical and computer engineering and mechanical engineering programs. These courses are selected carefully to provide a meaningful robotics engineering education to undergraduate students within four years. These courses include program design and object oriented programming from Computer Science, digital systems and embedded systems from Electrical and Computer Engineering, statics and control systems from Mechanical Engineering. In addition, the program requires software engineering, one course in social implications of technology, and one course in entrepreneurship. Within this structure, the program also allows for 3 advanced electives in robotics and 6 free electives.

RBE 1001 Introduction to Robotics

This course provides a broad overview of robotics at a level appropriate for first-year students. It serves as a stepping stone for students who haven't been involved with high-school level robotics courses and/or competitions. The goal is to capture students' enthusiasm about robotics early in their engineering careers and keep the students engaged. The course also serves as an introduction to Computer Science, Electrical and Computer Engineering and Mechanical Engineering as it is team-taught by faculty from each discipline. The course topics include static force analysis, electric and pneumatic actuators, power transmission, sensors, sensor circuits, C programming and implementation of proportional control in software. The objective is not to cover every topic in depth, but to provide students with a flavor of the subsystems forming a robot. The laboratory assignments use the VEX Robotics Development Kit, an off-the-shelf system, supported with the internally developed WPILib C software library for controlling dc motors, reading signals from various sensors including potentiometers, optical encoders, ultrasonic rangefinders, and gyroscopes.

Unified Robotics I-IV

The Unified Robotics I-IV course sequence forms the core of the Robotics Engineering program at WPI. The sophomore level courses, RBE 2001 and RBE 2002, introduce students to the foundational concepts of robotics engineering such as kinematics, circuits, signal processing and embedded system programming. The junior level courses, RBE 3001 and RBE 3002, build on this foundation to ensure that students understand the analysis of selected components and learn system-level design and development of a robotic system including embedded design.

RBE 2001-2002 Unified Robotics I-II

The sophomore-level courses, Unified Robotics I and II (RBE 2001 and RBE 2002), emphasize the foundational concepts of robotics engineering including kinematic linkage analysis, stress and strain, pneumatics and hydraulics, dc circuits, operational amplifiers, electric motors and motor drive circuits, sensors and sensor signal conditioning and embedded system programming using the C language [16]. The goal is to introduce students to the analysis of electrical and mechanical systems as well as the principles of software engineering. In both courses, the emphasis is on robotics applications, project-based learning and on the relationship among the electrical engineering, mechanical engineering and computer science disciplines as they apply to robotics. In combination, RBE 2001 and RBE 2002 provide a study of the foundations of robotics by integrating the fields of computer science, electrical engineering and mechanical engineering and prepare students for the advanced robotics courses.

Providing such a broad foundation in the 2000-Level robotics courses necessarily requires making compromises in the number of topics covered and the depth coverage in any one topic. It is simply not possible, given practical constraints on class time and student load to introduce students to everything they might require to engineer a robotic system. To balance these conflicting constraints, certain compromises are made in the delivery of the material to the students and in the exercises performed in the laboratory.

The first compromise relates to the material that is selected. Rather than attempt to teach all of the material that might normally be associated with a 2000-level course in any one discipline, the choice was made to pare the material to that which is essential to provide sufficient depth for the students to understand the related laboratory exercises. In this context, the emphasis in the classroom is on the most commonly encountered concepts rather than interesting special cases. In determining curriculum content, every topic is scrutinized to ensure that it is actually used for some significant purpose in the classroom, on homework, in exams and in the laboratory.

A second compromise relates to the laboratory exercises. In the laboratory students largely work with pre-packaged hardware and software elements which, while sufficient to reinforce concepts introduced in the classroom, hide many of the lower-level details of the devices they use in the laboratory. This provides a stable environment which allows students to focus on electrical, mechanical or computer science concepts introduced in class without worrying about these lower-level details. The result of these compromises is that students at the 2000 level have enough theoretical knowledge to "mostly" know how to approach a laboratory problem, and have a set of tools in the laboratory which allow them to rapidly prototype their solution. Many of these solutions fail on their initial attempt, which tends to prompt the students to stay engaged, revisit their errors and iterate on their designs. The result is a reinforcement of classroom theory, the development of better intuition from seeing ideas that don't work, and an increase in their willingness to iterate towards a better design.

RBE2001-2002 laboratories continue to use the VEX Robotics Development Kit supplemented by our WPILib software library. The lab assignments are designed to emphasize the theoretical background, such as simple linkage analysis, dc motor parameter identification, and sensor signal amplification [16].

RBE 3001-3002 Unified Robotics III-IV

Junior-level courses, Unified Robotics III and IV (RBE 3001 and RBE 3002) build upon the intuition that the students began to develop in the 2000-level courses [17-18]. It is in these courses that the students actually begin to understand and appreciate the details underlying their 2000-level experience. These junior-level courses provide a much deeper theoretical coverage of robotics, including: frame transformations, forward kinematics and inverse kinematics, manipulator dynamics, control systems, sensors, signals, reasoning with uncertainty, navigation, world modeling and path planning. In these courses students no longer have pre-packaged hardware and software components; they now are introduced to interrupt-based programming, software system architecture, object-oriented design and in-circuit debugging, and probabilistic algorithms.

The focus in RBE 3001 is on developing a deeper understanding of the types of devices they encountered in RBE 2001 and 2002. The course begins with an introduction to the Atmel AVR series of 8-bit microcontrollers which provide the computational platform for all of the experiments done in the laboratory. These experiments involve topics such as: real-time interrupt-based programming; control of a single axis robot arm; control of a multiple link robotic manipulator; characterizing encoders, accelerometers and magnetometers; characterizing infrared and ultrasonic rangers; and developing a simple, but complete, pick and place robotic system.

The focus in RBE 3002 is on integrating the information in the previous three courses into a complex robotic system. This course begins with an introduction to object-oriented programming and development of a framework based on a communication protocol between a PC and a robot. By incorporating hardware and software components developed in RBE 3001, the students perform experiments which involve topics such as: hardware/software partitioning; control of a mobile platform; multi-sensor data fusion, motion planning, world modeling and reasoning in the presence of uncertainty.

Advanced Courses

Once students complete the Unified Robotics sequence and all the supporting courses discussed above, they reach a level (both in depth and breadth) to take more advanced courses from the three departments supporting the RBE program. The students are required to select three advanced RBE-related electives from a list of courses. These courses include Human-Computer Interaction, Artificial Intelligence, Microelectronics, Signal processing, Kinematics, Mechatronics, and Robot System Engineering and Design [21].

RBE Capstone

The RBE capstone senior design experience (Major Qualifying Project or MQP) serves as the binding agent for the theory and practice learned in our core RBE courses and should demonstrate application of the skills, methods, and knowledge gained in the program to the solution of a problem that typically involves the design and manufacture of a robotic system. The senior capstone at WPI has been refined over 40 years of project-focused learning, since the WPI Plan was first adopted. Our recent experience with robotics capstone projects indicates that student learning is drastically improved as the students are extraordinarily enthusiastic about their projects, working within multidisciplinary teams (it is very common for capstone design project teams to include students from other disciplines) and communicating their “cool” robot projects to peers, faculty and representatives from sponsoring industries. Within the RBE program, robotic systems are viewed as solutions to problems using robotic technology – not as systems that contain an “ECE part,” an “ME part,” and a “CS part.” In other words, even if teams consist of students from traditional disciplines, there needs to be a focus on how disciplines interact with each other and how system-level decisions must be made in a manner that considers the cross-disciplinary ramifications of the decisions.

It should be noted that the capstone project, as implemented at WPI, is equivalent to three courses (1/4 year) and, in general, is completed in three 7-week terms. There are no lectures or labs that accompany the project in comparison to most universities where the capstone project is completed as part of the normal student coursework; rather student teams work independently on the projects with one-on-one supervision of a faculty member. Students meet regularly with their advisor. A final project report detailing the process and the final product and a formal presentation are required. Projects, and their public presentation, are such an important part of a WPI education that each spring an entire day–Project Presentation Day–is devoted to them and undergraduate classes are canceled. Project sponsors and other industry professionals are invited to attend the presentations. Upon completion of the project, the final reports and supporting documents become part of the university’s library catalog and are made available online.

As with any course of study, student project team members are often required to achieve specific learning outcomes. Although WPI has been focused on projects based education for well over thirty years it was only in 2009 that outcomes were approved for the capstone design: *Students who complete a Major Qualifying Project (capstone senior design) will:*

(a) apply fundamental and disciplinary concepts and methods in ways appropriate to their principle areas of study
(b) demonstrate skill and knowledge of current information and technological tools and techniques specific to the professional field of study
(c) use effectively oral, written and visual communications
(d) identify, analyze and solve problems creatively through sustained critical investigation,
(e) integrate information from multiple sources,
(f) demonstrate an awareness and application of appropriate personal, societal, and professional ethical standards,
(g) practice skills, diligence, and commitment to excellence needed to engage in lifelong learning.

Our early capstone advising experience and project outcomes were highly successful. Table 1 presents the capstone design projects completed in 2010 by design teams including RBE students.

Based on the project learning outcomes, faculty uses a variety of methods of measurement to collect data on the capstone design experience. We can divide the MQP assessment instruments into several categories.

Project Title	Team
Force Sensing and Haptic Feedback for Robotic Surgery	1 RBE 1 ME
Design of a Spoken Language Interface for Collaboration with an Autonomous Robot	1 RBE 1 CS
Reconfigurable Modular Mobile Robot Platform	3 RBE
Pneumatic Actuator Development for MRI Robots	2 RBE 1 ECE
Design of an Active-Assistance Balancing Mechanism for a Bicycle	2 RBE
A Multi-Weapon Auto Aiming and Trigger System for Rapidly Deployable Remotely Operated Armed Support Robots	1 RBE
Project Pele: Humanoid Robotic Programming - A Study in Artificial Intelligence	1 RBE 1 ECE 1 ME 1 MA
Design and Realization of an Intelligent Unmanned Ground Vehicle	3 RBE 2 CS 2 ECE 2 ME

Table 1: Robotics capstone projects completed in 2010 and the composition of design teams.

- **MQP Report Review:** 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 report review is completed by a committee consisting of RBE faculty. The committee reads all the MQP reports and collects survey data from faculty advisors to measure the quality of the MQP work and determine how well the ABET criteria a-k are demonstrated by the MQP.

- **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.

Assessment

Assessment is an integral part of the accreditation process. As an emerging engineering discipline [19], 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 satisfy. 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.

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 fourth 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 and will be discussed next.

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.

The continuous improvement process forms feedback loops that include objectives, faculty, courses and projects, students, and student work as shown in Figures 2. All assessment is performed relative to overall program objectives and specific educational outcomes corresponding to ABET/EAC outcomes (a) through (k) [20].

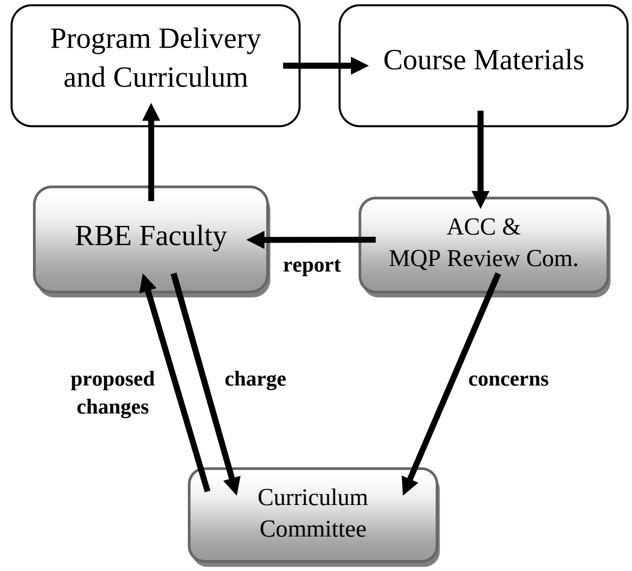

Figure 2: Curricular Revision Flow.

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.

To date, we have gathered extensive formal and informal input from the courses including course evaluations, additional surveys administered among students who completed the entire Unified Robotics sequence, faculty feedback as well as the MQP reviews. 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 and an observable increase in student perception of quality. An in-depth discussion of the assessment instruments, the samples of data collected and results have been recently presented in [20].

Conclusion

Robotics Engineering B.S. degree program at Worcester Polytechnic Institute is motivated by the growing market and demand in robotics technologies and the enthusiasm that the young generations demonstrate while working with robots. Furthermore, its multidisciplinary nature makes robotics an attractive field to recruit students and provide them with a broad engineering education. The program is an attempt to integrate electrical engineering, mechanical engineering and computer science concepts into a series of unified courses in robotics at the undergraduate level. In its third year, all indicators used in the assessment process lead to the conclusion that the implementation of the program has been successful.

References

1. Penn Engineering Grasp Lab, "Celebrating 50 Years of Robotics: Symposium and Poster Session," http://www.grasp.upenn.edu/events/elebrating_50_years_robotics, (accessed May 2010).

2. M. J. Mataric, "Robotics Education for All Ages," in *Proceedings AAAI Spring Symposium on Accessible, Hands-on AI and Robotics Education*, 2004.

3. L. Almeida, J. Azevedo, C. Cardeira, P. Costa, P. Fonseca1, P. Lima, F. Ribeiro, V. Santos, "Mobile Robot Competitions: Fostering Advances In Research, Development And Education In Robotics," in *CONTROLO'2000 4th Portuguese Conference On Automatic Control*, 2000.

4. J.A. Piepmeier, B. E. Bishop, K. A. Knowles, "Modern Robotics Engineering Instruction," *IEEE Robotics & Automation Magazine,* vol. 10, no. 2, 2003.

5. D. J. Ahlgren, "Meeting Educational Objectives and Outcomes Through Robotics Education," in *Proceedings of the 5th Biannual World Automation Congress*, 2002.

6. D. Chang, G. Jacoby, L. Shay, "Preparing and Advising a Fast-Track Education in Robotics," in *Proceedings of the 2007 ASEE Annual Conference & Exposition*, June 2007.

7. *Executive Summary World Robotics 2008*, http://www.worldrobotics.org/downloads/2008_executive_summary.pdf, (accessed May 2010).

8. Mass Technology Leadership Council, "Achieving Global Leadership: A Roadmap for Robotics in Massachusetts," http://www.asstlc.rg/oboreportfinal.pdf (accessed May 2010).

9. Computing Community Consortium, *A Roadmap for US Robotics: From Internet to Robotics,* http://www.us-robotics.us, (accessed May 2010).

10. G.T. McKee, "The Robotics Body of Knowledge," *IEEE Robotics & Automation Magazine*, vol.14, no.1, pp. 18-19, 2007.

11. National Academy of Engineering, *Educating the Engineer of 2020: Adapting Engineering Education to the New Century,* 2005.

12. E. Sklar, S. Parsons, M. Q. Azhar, "Robotics Across the Curriculum," in *Proceedings of AAAI Spring Symposium on Robots and Robot Venues: Resources for AI Education,* 2007.

13. C. Kitts and N. Quinn, "An interdisciplinary field robotics program for undergraduate computer science and engineering education," *Journal on Educational Resources in Computing*, vol. 4, no. 2, June 2004.

14. M. Ciaraldi, E.C. Cobb, D. Cyganski, G. Fischer, M. Gennert, M. Demetriou, F. J. Looft, W. R. Michalson, B. Miller, T. Padir, Y. Rong, K. Stafford, G. Tryggvason, J. D. Van de Ven, "Robotics Engineering: A New Discipline for a New Century," in *Proceedings of the 2009 ASEE Annual Conference*, Austin, TX, June 2009.

15. The WPI Plan, Worcester Polytechnic Institute, http://www.wpi.edu/Pubs/Catalogs/Ugrad/Current/theplan.html, (accessed May 2010).

16. M. J. Ciaraldi, E. C. Cobb, F. J. Looft, R. L. Norton, T. Padir, "Designing an Undergraduate Robotics Engineering Curriculum: Unified Robotics I and II," in *Proceedings of the 2009 ASEE Annual Conference*, Austin, TX, June 2009.

17. W. R. Michalson, G. S. Fischer, T. Padir, G. Pollice, "Balancing Breadth and Depth in Engineering Education: Unified Robotics III and IV," in *Proceedings of the 2009 ASEE Annual Conference*, Austin, TX, June 2009.

18. G. Fischer, W. R. Michalson, T. Padir and G. Pollice, "Development of a Laboratory Kit for Robotics Engineering Education," in *Proceedings of AAAI 2010 Spring Symposium on Educational Robotics and Beyond: Design and Evaluation,* Palo Alto, CA, March 2010.

19. M. A. Gennert & G. Tryggvason, "Robotics Engineering: A Discipline Whose Time Has Come," *IEEE Robotics & Automation Magazine,* pp. 18-20, June 2009.

20. M. A. Gennert, F. J. Looft, G. Tryggvason, T. Padir, L. Schacterle, "Robotics Engineering: Assessing an Interdisciplinary Program," in *Proceedings of the 2010 ASEE Annual Conference*, Louisville, KY, June 2010.

21. *Robotics Engineering Advanced Systems Electives,* http://www.wpi.edu/academics/ajors/BE/electives.html (accessed June 2010)

Biographical Information

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