

A Robotics Engineering Major

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Abstract—Robotics is experiencing rapid growth, driven by both supply of inexpensive components and demand for automated and autonomous devices, yet no single discipline provides the breadth demanded by robotics in the future. To meet this need, Worcester Polytechnic Institute has instituted a Robotics Engineering degree program to educate future robotics engineers and prepare students for graduate work in robotics. The program represents a joint effort by a team of faculty and staff from the Departments of Computer Science, Electrical & Computer Engineering, and Mechanical Engineering. The curriculum draws extensively from the above fields plus mathematics, with additional courses from science and management.

This paper outlines the principles that guided program development: clearly articulated objectives, program breadth, flexibility, accreditability, feasibility within four years, and consistency with WPI's overall educational philosophy. The curriculum is described in detail, including the Unified Robotics course sequence and senior-level projects. We list synergies with other programs, and review lessons learned.

I. INTRODUCTION

Robotics—the combination of sensing, computation and actuation in the real world—is experiencing rapid growth, driven by both supply of inexpensive components and demand for automated and autonomous devices. Currently, 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. To meet this need, Worcester Polytechnic Institute (WPI) has instituted a Robotics Engineering degree program that will contribute to the growth of the robotics industry by educating engineers to work in that industry and preparing students for graduate work in robotics. In addition, this program has the potential to increase undergraduate STEM enrollment by building on robotics competitions [1] to attract a diverse student body.

II. PROGRAM OUTLINE

The Robotics Engineering (RBE) major program represents a joint effort by a team of faculty and staff from the Departments of Computer Science, Electrical & Computer Engineering, and Mechanical Engineering. The curriculum draws extensively from the above fields plus mathematics, with additional courses from science and management.

The following principles guided program development: The program should have **clearly articulated objectives**, and the curriculum should ensure that those goals are in fact met, not merely paid lip service. It should be a **broadly-based** program, while retaining student **flexibility** in course selection where possible. The program should be **accreditable** by ABET, just like any other engineering degree. It should fit within **four years** and be consistent with WPI's overall **educational philosophy**.

A. Educational Objectives

One of the earliest tasks was to define a set of educational objectives, which "...are to educate men and women to

- Have a basic understanding of the fundamentals of Computer Science, Electrical & 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." [2]

B. Broadly-based Program

To provide the necessary breadth, the Robotics Engineering major curriculum requires a moderately advanced background (typically, junior-level courses) in each of the foundational disciplines. Within each, we identified target courses that students must reach.

Computer Science: Algorithms and Software Engineering,
Electrical & Computer Engineering: Embedded Computing Systems, and
Engineering Science/Mechanical Engineering: Statics and Controls.

We rely on the recommended background course structure (WPI does not have rigidly enforced course prerequisites) to ensure that students are sufficiently prepared to take these courses. A useful exercise—mandated by a faculty academic

committee—was to list all courses implied by the recommended background course structure. This exercise forced a replacement of some proposed courses by other courses with less onerous backgrounds.

Notably absent from the required courses are some that might reasonably be expected of Robotics Engineers. For example, neither Artificial Intelligence nor Design of Mechanisms is required. Instead, they are assigned to a set of restricted electives. These were among the compromises made to ensure a feasible four-year curriculum. Our reasoning is as follows: Given a choice between requiring Software Engineering vs. Artificial Intelligence, it was felt that an engineer who understood proper software design methodologies and processes but lacked expertise in AI will be more useful than an engineer who understands AI but cannot design good software.

C. Flexibility

Many WPI students spend a term or more off-campus at Project Centers to satisfy general education or major-specific project requirements. Thus, flexibility is an important consideration. It is realized by minimizing the specifically required courses, providing alternative courses to satisfy requirements where practical, and offering courses as often as possible, often twice a year. For example, the program includes three robotics-related electives and two unrestricted electives. This allows multiple paths through the curriculum.

D. Accreditation

Robotics Engineering is not recognized by ABET [3] as a distinct engineering discipline, hence there are no program-specific criteria to follow for accreditation. Nonetheless, we planned the program as if it were accreditable. Accreditation by ABET/EAC is important for several reasons.

- It adds credibility to the program with prospective students and their parents who want some assurance of program quality.
- It adds credibility to the program within a largely engineering- and science-oriented faculty.
- Licensure as a Professional Engineer generally requires that engineers graduate from an ABET/EAC accredited program [4].
- ROTC scholarships for students attending engineering programs are limited to ABET/EAC accredited programs.
- Accreditation reviews can help justify resource allocation.

The RBE program is based on program objectives and outcomes, and with mathematics, science, and engineering and design components consistent with general criteria for accreditation. Such a program could be accreditable under General Engineering, which has no program-specific criteria, and we expect to apply for accreditation eventually¹.

Program criteria for Mechatronics Engineering are currently under consideration by ABET. These criteria refer to required

chemistry and materials components, which we have not included in our program. Hence, despite the similarities between Mechatronics and Robotics Engineering, accreditation using Mechatronics Engineering criteria appears infeasible.

E. Four Years

When general education requirements are accounted for, this became one of the more difficult principles to adhere to. As noted above, compromises were made to achieve this goal. We expect to eventually develop a five-year B.S./M.S. program in Robotics Engineering that would include topics left out of the B.S. program.

F. Educational Philosophy

All WPI programs include a balance of theory and practice in a project-oriented framework that also addresses humanistic concerns. Robotics Engineering is a perfect fit.

III. CURRICULUM DETAILS

A first pass at laying out a typical student schedule showed that we could satisfy all of the above desiderata using only existing courses. However, apart from a single introductory robotics course and a senior-level robotics project, there was no robotics in the schedule, clearly an unsatisfactory situation. We then replaced four sophomore and junior-level courses in CS, ECE, and ME with a four-course sequence Unified Robotics I–IV, inspired by MIT’s Unified Engineering course sequence [5].

A. Unified Robotics

Unified Robotics is the centerpiece of the Robotics Engineering curriculum. Each Unified Robotics course includes content from each discipline, in effect slicing the curriculum across disciplines, rather than along them. The courses and foci are:

Unified Robotics I: Electrical–mechanical power conversion and computer control,

Unified Robotics II: Interaction with the environment through sensors, feedback and decision processes,

Unified Robotics III: Actuator design, embedded computing and complex response processes, and

Unified Robotics IV: Navigation, position estimation and communications.

We plan to team-teach these courses, using a three-faculty member team comprising one person from each of CS, ECE, and ME in each course initially. To increase the attractiveness of these courses to faculty and reflecting the time demands of coordinating among faculty, teaching one-third of two Unified Robotics courses counts the same toward faculty course assignments as teaching a single course in a non-team manner.

¹ABET requires at least one person to have graduated under the program requirements in order to accredit a program.

B. Robotics Electives

Robotics electives are included in the program to give students the opportunity to delve more deeply into some aspects of engineering that relate to robotics. Students may focus their electives in a single area such as CS, ECE, or ME, or, if they prefer, remain robotics generalists. We emphasize that concentration within a robotics subfield is not required.

Within the robotics electives, students must take at least one of Artificial Intelligence, Wireless Networking, and Design of Mechanisms. Taking all is allowed, but is neither encouraged nor discouraged; students should select the most appropriate mixture of electives for themselves. Other electives are more loosely tied to robotics, including a wide range of courses in CS, ECE, and ME such as Operating Systems, Human-Computer Interaction, Networks, Signal Analysis, Machine Design, Mechatronics, Industrial Robots, and Nanotechnology.

C. Senior Projects

All WPI students must complete a senior-level project in their major field of study. For RBE students, this constitutes a capstone design experience in Robotics Engineering. Projects are equivalent to three courses of academic work, and may be spread over several terms or completed in a single project-intensive term. Students typically work in teams of two to four students, although single-person projects and larger teams are also possible. A faculty member in the major advises the work.

Students are expected to take relevant coursework before the project begins. The project work itself typically starts with a formal project proposal, including literature review, clearly defined approach, and schedule with milestones. Projects conclude with a report and presentation to faculty and students. Many project reports become conference papers; having students at all levels as co-authors is highly valued at WPI.

Project ideas come from several sources: faculty may have topics that relate to their research or other interests, industry often sponsors projects (and is charged a project fee for the privilege), and students may explore their own project ideas with faculty approval.

Industry-sponsored projects deserve special mention. Some of these are performed on-campus; others take place at the company site. For companies near campus, students can commute as needed. Farther away, students live near the company as part of a residential Project Center. Whichever model is used, industry gets a close look at a potential future hire and also gets the opportunity to implement a small project that they otherwise lack the staff to commit to. Students enjoy the experience and find themselves well-prepared for future employment or graduate school.

Even before the RBE program begins, students from various majors have been working on robotics projects. Sample projects in 2006–07 include a solar-cell / rechargeable fuel cell powered robot and a roof inspection robot sponsored by an insurance company.

D. Mathematics and Science

In order to obtain a solid foundation in mathematics and science, students must take at least seven courses in mathematics including Differential and Integral Calculus, Differential Equations, Discrete Mathematics, and Probability or Statistics. In science, students take one course each in Mechanics and Electricity & Magnetism, and another two unspecified science courses.

E. Social Implications

Another curricular element is a requirement for a course in Social Implications of Technology, which is a common program requirement at WPI. This requirement contributes to the program outcome that students have an ability to design within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability. It also contributes to students' development of an understanding of professional and ethical responsibility. This requirement may be satisfied by a range of social implications courses in Computer Science, Government, Interactive Media & Game Development, and Social Sciences.

F. Entrepreneurship

To encourage students to become “enterprising engineers” [6], there is a single-course requirement in Entrepreneurship. A course in this area could include identifying ideas for new businesses, feasibility analysis, evaluation for appropriateness, and business plan development.

We strongly believe that engineers need to “think outside the cubicle” and must understand the business contexts within which they operate. This is important not only for entrepreneurs who deal with venture capitalists, lawyers, and other financial and marketing resources to start up new companies, but also for intrapreneurs who generate new business ideas and plans to present to senior management within their existing companies. Industry has reacted with great enthusiasm to the entrepreneurship component.

IV. SYNERGIES

Engineering synergizes well with another recently added program in Interactive Media and Game Development [7]. The two programs share a common theme: the close interaction of humans with computational systems. The former emphasizes autonomous systems performing physical tasks for humans; the latter emphasizes semi-autonomous systems generating virtual worlds for humans.

The pool of students interested in either has a natural affinity for the other. As the avant-garde of engineering students, they are apt to share certain characteristics: unconventionality, risk-taking, and high motivation. RBE and IMGD lend themselves well to double-majors, as would any of CS, ECE, and ME. An RBE major with a minor in an allied field would also be an attractive combination.

Because WPI does not (yet) offer graduate degrees in Robotics Engineering, B.S./M.S. students are allowed to continue from RBE to CS, ECE, or ME for graduate studies,

allowing more in-depth work in a specialty than is possible within the constraints of the RBE B.S. program. This is strongly encouraged, both for the educational value, and for the potential to turn senior projects into more enduring contributions through M.S. theses and research publications.

V. LESSONS LEARNED

We have learned several key lessons in developing the program. These lessons may be broadly applicable to a range of universities considering Robotics or other innovative programs.

- Vision and passion are critical, yet cannot replace a thorough business plan when seeking administration approval. Education is a business.
- A bottom-up approach to curricular innovation is more likely to succeed than top-down. Faculty will devote enormous energy to causes they believe in.
- Stick to one's guiding principles. For example, we were pressured to drop the entrepreneurship requirement in favor of additional technical coursework, yet that would have gutted the entrepreneurial objective, so it was retained. Not surprisingly, industry enthusiastically concurs.
- Be willing to compromise on most anything else. For example, courses in AI and Kinematic Design could not be required without violating some principle, so they became electives.

- Communication is critical, including within the team, with other faculty, the advisory board, and administration.
- Be bold! You might just get what you ask for.

VI. CONCLUSIONS

It is too early to measure the success of the program. However, every indication points toward success. Potential student interest at admissions events has resulted in standing-room-only sessions in Robotics Engineering, freshman registration for Robotics Engineering courses exceeds expectations, and faculty, staff, and administration are firmly committed to the program. For more information, see <http://robotics.wpi.edu/>.

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