
Conceptualising educational approaches in introductory robotics

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Abstract This paper considers 'Introduction to Engineering Design–Mobile Robotics,' a first year course in the undergraduate engineering programme at Trinity College. A highlight of the course is a team-based semester-long project in which students design and build fire-fighting robots and participate in the international robot competition. Course contents, hands-on learning experiences, and assessment methods are described. Course assessment and evaluation showed that it exposed first-year students to practical and philosophical dimensions of engineering design, successfully addressed many basic ABET outcomes, and elicited a positive student reaction.

Keywords design course; fire-fighting contest; mobile robotics; outcomes assessment; team projects

A robot is a system that can be programmed to perform a range of mechanical functions and that responds to sensory input under automatic control. It constitutes a mechatronic engineering product, the synergetic combination of mechanical, electrical, computer, and information technologies.¹ As a specific category of mechatronic product, robots can perform functions normally ascribed to humans or animals, to imitate them and interact with them, or to act autonomously in various physical environments. In addition to the engineering disciplines, robotics deals with physiology, behaviour science, and various other subjects in science and the humanities. Robotic systems can relate to most processes in nature, human practices, and interactions with the environment. Their potential as educational tools for teaching and learning various subjects in technology, science, and humanities is unlimited.

The reasons making robotics especially effective at the introductory level of engineering education are as follows:

- 1 From the beginning of their studies students acquire a holistic 'mechatronic' view of electrical, mechanical and computer engineering, and shape personal inclinations in these professional areas.
- 2 Students acquire basic knowledge and experience that is important for their success in more advanced engineering courses.
- 3 From their first year of studies students become involved in self-directed learning, interdisciplinary design, teamwork, professional communication, technical invention, and research.
- 4 Students learn to investigate physical environments and human factors that determine engineering designs.

- 5 Intensive practice in solving diverse mental and physical tasks in the robotics medium can promote development of student intelligence and creativity.

A rapidly growing literature on robotics as an instructional medium in university and secondary school education has focused on describing initiatives, courses, and instructional tools. However, limited progress has been made in conceptualizing learning and instruction processes that underlie successful introductory robotics courses. Important open questions relate to prerequisite knowledge, integration of disciplines, learning by design, teamwork, robotic competitions, assessment, and evaluation. Finding answers to these questions requires educational research, which will help improve teaching and offer the means to evaluate and disseminate robotics programs. To achieve these goals, the educational research should be closely connected with practice and fit the criteria of fruitfulness, generality, testability, and coherence.²

In this paper the authors consider their experiences in teaching robotics as an introductory engineering subject with focus on analysis of learning processes and outcomes.

Educational background

Educational robotics relies on core concepts of modern engineering education. Seymour Papert and his adherents developed the concept of *constructionism* to characterise learning processes in which a learner is involved in the creation of external and sharable artefacts.³ The learner uses artefacts as 'objects to think with' in order to explore, embody, and share ideas related to the topic of enquiry. Studies showed that this approach could be effectively used to educate students of all ages and experience levels and to stimulate their intellectual maturity.⁴ The constructionist approach was applied to teaching robotics first in the MIT undergraduate course 6.270 'LEGO Robot Design Competition Project'.⁵ In the course a robot was introduced as 'the object to think with' and the project-based curriculum focused on designing, building and operating autonomous robots.

The concept of principal educational outcomes is the other important premise for development of introductory robotics courses. In its EC2000 criteria, the Accreditation Board for Engineering and Technology (ABET) formulated a list of basic educational outcomes for all modern engineers with focus on systems approaches, cross-disciplinary linkages, and project-oriented learning.⁶ EC2000 required that all engineering programmes develop such core skills as 'an ability to design a system, component, or process to meet desired needs', and 'a recognition of the need for, and an ability to engage in life-long learning'. Engineering programmes are evaluated by measuring their results in achieving the stated educational outcomes.

The content and strategies of professional practice in engineering education have been principally revised in the concept of 'reflective practice'. As stated by Schon,⁷ reflective practice is solving problems that are unfamiliar and not initially clear, through an iterative 'reflection-in-action' process of constructing, implementing, and

evaluating new strategies. The main form of reflective engineering practice is creative, holistic design. Schon proposed also to extend this practice throughout the engineering programme, as opposed to traditional practice given only during the senior year of studies.

The authors discussed the principal educational outcomes in introductory robotics courses in a previous paper.⁸ This paper presented results of a survey study conducted at the Trinity College Fire-Fighting Home Robot Contest (TCFFHRC). Data obtained from the contestants at the TCFFHRC 1999 and 2000 gave an argument in favour of robot contests for education in interdisciplinary team-based design. With this, the need for more comprehensive analysis of educational outcomes in introductory robotics courses was noted.

Fire-fighting robotics

Robotics offers many advantages as the basis of a learning-by-making curriculum, in which students in groups design, build, and operate robots to implement intelligent assignments.⁹ Competition between groups can significantly stimulate learning motivation of students, and intensify the learning process.¹⁰ Robotic fire-fighting will be considered below as one such assignment.

The Trinity College Fire-Fighting Home Robot Contest^{11,12} has attracted designers of all ages, affiliations, and levels of experience from around the world. Regional contests have been held in North America, Asia, and the Middle East. Students from more than 60 universities, including MIT, Yale, The US Naval Academy, Tufts, New Mexico Tech, and Oklahoma State, have taken part. The TCFFHRC is the world's largest truly open robotics competition.

The TCFFHRC presents a challenging design problem: to develop a fully autonomous, small mobile robot that can navigate through a model house (an 8 ft by 8 ft maze), find a candle, and extinguish it in a race against the clock. The maze has four rooms and connecting hallways, and the candle is placed at random in one of the rooms. The robot must navigate autonomously to within 12" of the flame before extinguishing it. Contest rules are published on the web site.¹³ The contest has provided the impetus for curriculum and course development in several countries, notably the USA, Israel, and China (Fig. 1).

Robotics at Trinity College

Trinity is a selective liberal arts college that offers an ABET-accredited general engineering programme. In the Trinity Engineering curriculum, students take basic science and mathematics courses, four engineering core courses, and electives that round out an area of concentration. Three areas of the curriculum take advantage of robotics: (1) a robotics study team which focuses on mobile robot research and development; (2) senior design projects required for graduation; and (3) ENGR 120, a new introductory design course aimed at first-year students.

The Robotics Study Team (RST) was established in 1996, and it has engaged some

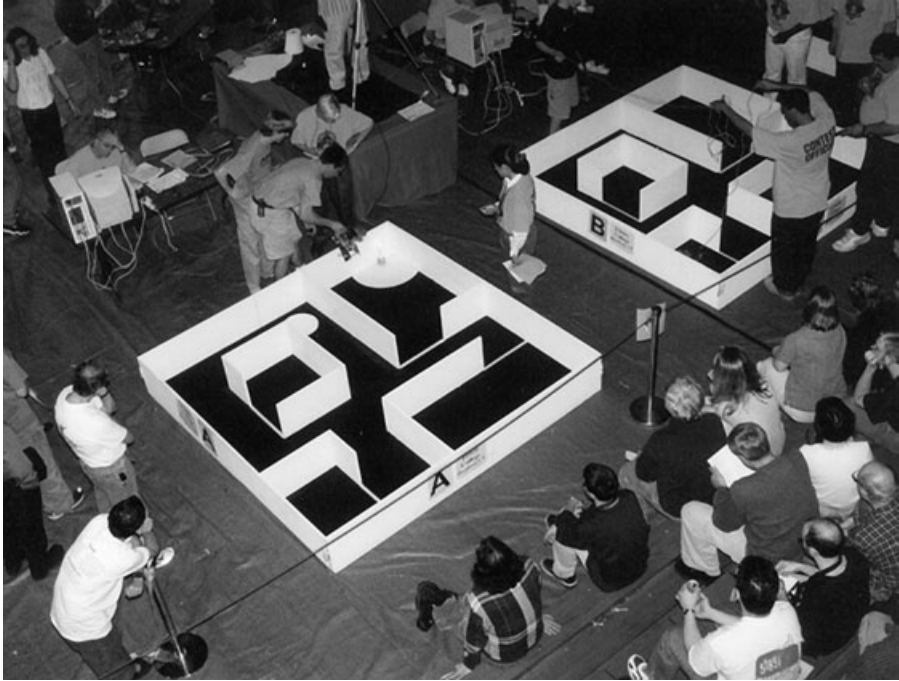


Fig. 1 *View of fire-fighting robot contest.*

10–15 students each semester in the design of mobile robots for competition. Members of the RST include students from all four college years. Each RST member joins a disciplinary group (electrical, computer, mechanical, sensor) that reports in the weekly RST seminar on research and development progress. The more experienced RST members serve as mentors and teachers, and the team builds its knowledge base in robotics from year to year. The RST's achievements include first, second, and fifth-place finishes in the TCFHRC, first- and second-place finishes in regional fire-fighting contests (Tel-Aviv and Colorado) and an eighth-place finish in the International Ground Vehicle Competition (IGVC).¹⁴ Figure 2 shows the RST's MiniBob, the second-place robot in the 2001 Expert Division of the TCFHRC. Minibob uses a MC68HC332 microcontroller, commercial and student-designed ranging sensors, three team-developed printed circuit boards, and a micro-stepper four wheel drive system. Using sensor-based fuzzy logic control, MiniBob can navigate through any maze with an arbitrary starting location.

Trinity engineering students have completed more than 15 senior projects related to mobile robot design. These include a capacitive proximity sensor for robotics, a microcontroller-to-DSP interface, DC motor controller peripherals, and ALVIN – an autonomous land roving robot that has competed in the International Ground Vehicle Competition (IGVC 2001).¹⁴ Figure 3 shows the IGVC Robot ALVIN.

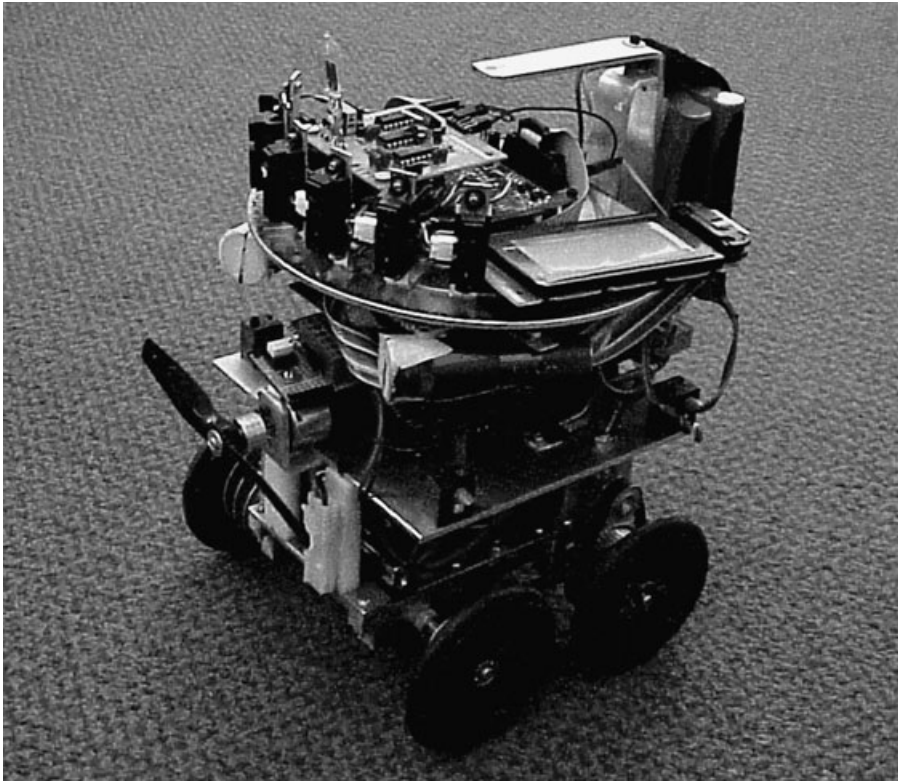


Fig. 2 *Trinity College fire-fighting robot MiniBob.*

First-year Engineering Design course

ENGR 120: Introduction to Engineering Design–Mobile Robotics is a first-year, elective, three-hour lecture course that was offered in the Spring semesters of 2000 and 2001 with enrolments of approximately 20. ENGR 120 student background in engineering is limited, but their high-school preparation in mathematics and science is strong. A highlight of the course is a team-based semester-long project that requires students to design, construct, and optimize a competitive fire-fighting robot.

The main goals of the course are:

- 1 to provide ‘real’ engineering experiences in the first year;
- 2 to expose students to both practical and philosophical dimensions of engineering design;
- 3 to offer an academic experience early in the student’s career that encourages the realization of a number of the basic ABET outcomes a-k; and;
- 4 to introduce students, early in their academic careers, to the rigors of engineering studies and to clarify their view of Engineering as a possible major field.



Fig. 3 *Trinity IGVC robot ALVIN.*

Table 1 presents specific educational objectives, strategies and activities, and assessment bases that pertain to ENGR 120. The reader will find further information in Ref. 11.

One-half of the ENGR 120 lectures (thirteen lectures, one each week) present mechatronics topics that prepare students for the fire-fighting robot design project. These lectures focus on (1) electrical engineering, mechanical engineering, and programming topics presented in the text by Martin, Chapters 1–5,¹⁵ and (2) special topics related to sensors and interfaces used in the fire-fighting robots. Graded quizzes, homework problems, and examinations gauge student learning of these topics throughout the semester.

The other thirteen lectures develop students' understanding of the nature and intellectual locus of engineering design. In the first four weeks of the term, teams conduct seminar presentations of readings from Petroski¹⁶ and Ferguson,¹⁷ authors who discuss such topics as invention, creativity, design constraints, economic issues, and patents. Each ENGR 120 team leads a seminar session where students present the main ideas of a book chapter and lead a class discussion of the main topics. Those who are not members of the presenting team prepare written questions for discus-

TABLE 1 *ENGR 120 objectives and educational strategies*

Objective	Strategy/Activity	Assessment bases
1. Introduce basic design topics from EE, ME, programming	Lectures on mechatronics topics related to mobile robot design	Quizzes, examinations, homework problems
2. Develop understanding of design process, develop vocabulary related to design, introduce philosophical side of design	Team-led class discussions of readings on engineering design	Oral presentations, communication review, level of preparation for discussion
3. Impart understanding of engineering profession	Guest lectures by engineering professionals and faculty members	Written summaries of guest lectures, class participation
4. Engage in design of industrial product, in cooperation with engineers from industry	Team-based solution to design problems posed by professional engineers	Team oral presentations, technical memoranda, written project reports
5. Develop practical skills (soldering, wiring, mechanical construction), teach the iterative process of engineering design	Design fire-fighting robot; build and improve; test and evaluate; compete	Skill tests, performance evaluation, team performance in robot Olympics
6. Expose students to system design, sensors, microcomputer interfacing, design using modern engineering tools	'Just in time' learning in robotics lab; hands-on workshops; expose students to engineering tools and methods	Progress reports, logbook, product evaluation
7. Promote teamwork and cooperative learning	Team-based assignments	Team project reports specifying personal contributions of team-members, logbook

sion; in this way, all are prepared. These seminars offer the presenting teams opportunities to develop and sharpen communication skills, and the teams are graded on their presentations.

Guest lecturers, who are representatives from industry and faculty from electrical, mechanical, and biomedical engineering, help students to develop a broad understanding of the engineering field. These professionals describe the fields in which they work and discuss such topics as team practice, modern corporate environments, entrepreneurship, and ethical and societal implications. Such knowledge, gained early in the academic career, helps students to make well-informed decisions about whether to pursue an engineering major and what field of engineering to enter. Students respond to these lectures by writing graded essays that reflect upon and assess each presentation.

Guest lecturers also expose students to engineering design as practiced in indus-

try. These guests have included the leader of a design and test group at a large aerospace corporation and the head designer of a biomedical instruments team. Each year the biomedical engineer has presented design case studies and has presented design problems that ENGR 120 teams address in a two-week assignment. In 2003 these problems included design of cardiac defibrillators, remote heart monitors, diabetes monitors, and automated medication reminders. Each team engaged one of these design problems, considering such issues as efficiency, control panel layout, human interface, component layout, simplicity, safety, patenting, maintainability, and cost. Students received critiques of their work from the engineers via electronic mail, and they were graded on the quality of oral and written reports. These design projects, undertaken five weeks into the semester, helped students to gain confidence. Students were surprised to see that many of their ideas had been incorporated in commercial products.

A semester-long project, design of a fire-fighting robot, promotes realization of the last three objectives in Table 1 – development of practical skills, hands-on exposure to engineering tools and techniques, and promotion of teamwork and cooperative learning. Development of practical skills is inherent in the process of making a fire-fighting robot as is exposure to a practical design methods, tools, and devices – including microcomputers, sensors, and CAD tools. A semester-long series of workshops engages students in hands-on exercises that lead, by term's end, to a complete working robot. All of this work is accomplished by teams, who document their work in a team logbook and who give regular graded team progress reports in class. The logbook contains a written record of all team meetings, project management plans, and experimental data. The following section discusses teamwork and workshops in greater detail.

Teamwork, workshops, and robot design

Each year's ENGR 120 class of 21 students is divided into seven design teams whose membership is chosen at random. Each team attends a weekly one-hour lab workshop, conducted by teaching assistants who are third- or fourth-year engineering undergraduates. The TA's are members of the Trinity Robot Study Team (RST) and have considerable experience with mobile robot development. Workshops are held in the Robot Engineering Laboratory (REL), which is equipped with PC and Macintosh computers, printers, electronic instruments, software tools, and a fire-fighting contest maze. The ENGR 120 students have card-key access to the REL and are free to work there at any time. Workshop exercises develop engineering skills through hands-on experiments in mechanical design, sensor development and interfacing, programming, and system integration (Table 2).

Each team is provided a design kit that includes a Lego Mindstorms kit, a Handy-Board computer with IC software,¹⁸ IR ranging sensors (Sharp GPD-12), and flame sensors. A few large Lego pieces (plates and girders) are added to each kit to ease design of robot bases. Students are encouraged to add other components as they see fit. Replacing the Mindstorms Brick, the Handy Board affords increased memory space, ease in interfacing, and a well-tested programming environment. Experience

TABLE 2 ENGR 120 workshop activities

Workshop	Goal	Primary Activity
1. Programming of fire-fighting robot Phoenix (winner of 1998 TCFHRC)	Introduce mobile robot programming using Interactive C (IC)	Develop IC programs that implement dead reckoning, wall following, and maze navigation
2. Introduction to the Handy Board	Expose students to the Handy Board and to PC-based cross-software development	Develop simple IC programs to run on the Handy Board
3. Design of HandyBug Lego robot	Exercise team approach to building first robot; expose students to touch sensors, motor control, interfacing; building programming skills	Design and build wall-banger robot; wire sensors; write IC programs that detect sensor closure and control robot motion (forward, reverse, turning)
4. Braitenberg Vehicle Design	Introduce students to applications of circuit laws (Ohm's Law, Kirchoff's Laws); apply to photosensor circuit	Modify HandyBug design so it follows light sources and responds to collisions
5. Ranging Sensors	Introduce IR ranging sensors and applications in navigation	Build a cable for the sensor, add low pass filter to eliminate noise. Take data and create sensor calibration curve
6. Basic Navigation	Introduce negative feedback concept via sensor-based wall following	Develop wall following algorithm, code it in IC, and test
7. Flame and Stripe Sensor Design	Introduce IR photodiodes and applications	Develop passive and active sensors for flame detection and contrast detection. Program robot to react to data from these sensors
8. Maze Navigation	Fine-tune maze navigation algorithms	Obtain reliable maze navigation. Add and test fire-extinguishing system
9. Optimize Robot (3 weeks)	Prepare for competition. Compete in preliminary contest	Improve sensing systems, codes, efficiency, etc.

in ENGR 120 indicates the Mindstorms kit contains a rich variety of components and affords quick prototyping of mechanical designs. An alternative approach, in which students are provided a programmable platform with a fixed chassis, would not encourage creativity in mechanical design.

Development of the fire-fighting robot requires ENGR 120 teams to design a mechanical system including motor placement, mounting, and gearing; computer-controlled bi-directional motor drive system; sensors for obstacle detection and

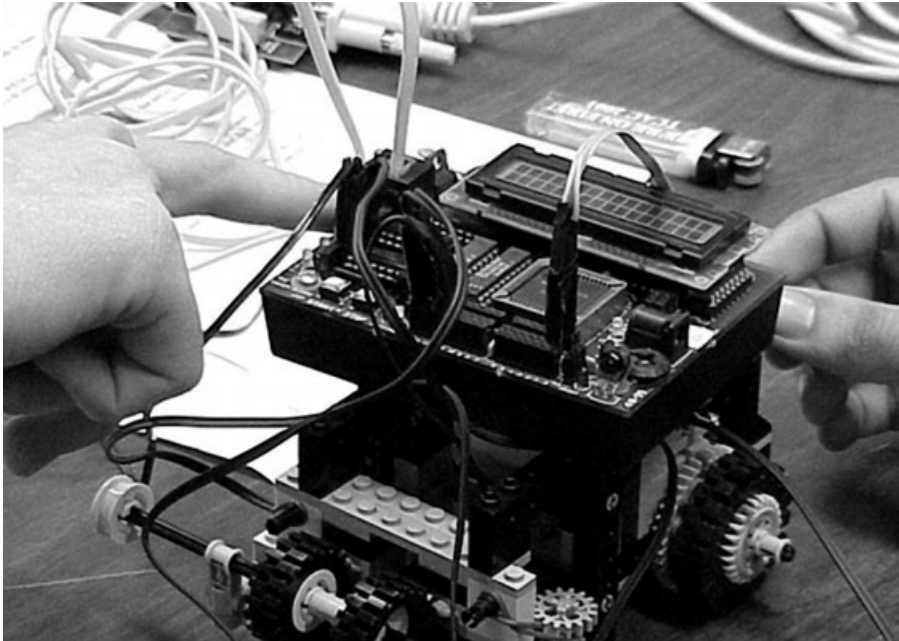


Fig. 4 ENGR 120 Fire-fighting Lego robot under construction.

flame detection; and real-time software that reads sensor data and issues motor controls. Completion of these tasks develops students' technical skills, including soldering, wiring, and other construction methods. As the contest nears, students focus on optimizing their designs by reducing weight, choosing the best gear ratios, improving motor control accuracy, improving maze navigation algorithms, and increasing reliability. A fire-fighting Lego robot developed in ENGR 120 is shown in Fig. 4.

Resources

ENGR 120 required a variety of resources given its diverse goals and wide range of activities. Three teaching assistants were employed to lead workshops and provide technical support to the teams. Seven other students served as team mentors. The course taxed the laboratory, which received heavy 24-hour per day use as the contest approached.

The course required students to purchase Fred Martin's new text,¹⁵ which presents a sequence of robot design exercises that begin with simple motion and move to sensor-based navigation. The text carefully presents the design of the first robot (a wall-banger) that ENGR 120 students build and their second robot, a light-seeking Braitenberg Vehicle. The text introduces fundamentals of mechatronics with presentations about sensors, motors and gears, and displays, for example. Along with

introductions of such topics as data acquisition, motor control, and navigation, the text presents short C programs that control these processes. The authors endorse this integrated, 'just in time' approach to programming instruction for mobile robots. The last chapter in Martin considers material that is beyond the scope of this course, but the chapter is a good resource for more advanced students who seek a deeper understanding of sensors and interfacing. The experience in ENGR 120 recommends the text highly.

The instructor instituted a programme of student-to-student mentoring in ENGR 120, starting in the spring of 2001, inspired by a similar approach described by Knight *et al.*¹⁹ The primary responsibilities of ENGR 120 mentors were to attend team meetings and workshop sessions, facilitate project planning and management, stay aware of interpersonal problems on the teams, help teams to develop and adhere to schedules, and provide limited technical assistance. The mentors meet once per week with the instructor, and they were required to write a mid-term paper and a final paper in which they assessed their experiences. An evaluation of the mentoring program,¹¹ indicated that students found the mentoring programme to be highly beneficial. Key benefits included regular meetings between mentors and teams, peer-to-peer instruction, and assistance with technical details.

Many written comments indicated a positive response to the mentoring programme and to the prospect of continuing it; the following is typical:

It really helped to have someone who had actually done what we were doing . . . helped with setting goals, easy to communicate with, posed problems. [Mentor] helped us to keep on top of everything and helped us to reach our objectives.

Evaluation

The educational objectives and outcomes for ENGR 120 (Table 1) were assessed through two surveys: (1) a standard Trinity engineering department course evaluation form (the SCE), and (2) a robot contest participation survey administered by the authors. Since the SCE and the robot contest survey instruments were already in place, we did not construct an evaluation procedure specifically for this course.

At the end of each semester Trinity engineering students fill out the SCE for each of their courses. The SCE assesses student views of the course format, instructor, and execution. The SCE also presents students a series of questions designed to relate course learning outcomes to the standard outcomes a–k of the Accreditation Board for Engineering and Technology (ABET).²⁰ SCE survey results are compiled and presented to ABET as part of the self-study phase of the accreditation process. Students also have the opportunity to write comments on the SCE forms.

There is strong correspondence between the objectives stated for ENGR 120 (Table 1) and the ABET criteria a–k. One of the authors (Ahlgren) examined SCE data from a total of 31 students who completed the 2000 and 2001 ENGR 120 classes, in order to evaluate student achievement of ABET outcomes.²¹ The ABET outcomes are listed in the first column of Table 3. The second column points out the ENGR 120 objectives related to each of the outcomes. The third column presents

TABLE 3 ENGR 120 students progress in ABET outcomes

ABET Outcomes a–k	Related ENGR 120 objectives 1–7	Rating on SCE, 5 pts max.
(a) Ability to apply knowledge of mathematics, science, engineering	Objective 1	4.41
(b) Ability to design and construct experiments	Objectives 2 and 4	4.73
(c) Ability to design a system, component, process	Objectives 1, 2 and 4	4.31
(d) Ability to function on multidisciplinary teams	Objective 7	4.83
(e) Ability to identify and solve engineering problems	Objective 6	4.65
(f) An understanding of professional and ethical responsibility	Objective 3	4.03
(g) An ability to communicate effectively	Objective 3	3.72
(j) Knowledge of contemporary issues	Objective 3	4.16
(k) Ability to apply techniques, skills, and modern engineering tools	Objectives 5 and 6	4.71

the average grades which express students' progress in the ABET outcomes on a five-point scale where a score of 5 indicates strong agreement, 3 indicates neutral response, and 1 is strongly negative. The results indicate that the course has successfully encouraged students to meet many of the basic ABET educational outcomes in their first year of studies.

The SCE also solicits students' written comments, which included the following in the 2000 and 2001 survey:

- *On teamwork:* 'What I enjoyed most about this course was the hands on experience. Actually designing, building, and programming a robot was far more educational than simply reading . . . The team aspect was an enjoyable aspect of the course.'
- *On gaining understanding of engineering design:* 'I learned a lot about the process of design and its role in the field of engineering. I also learned a lot about programming and how frustrating it can be at times! . . . I think the course should have a full lab (3 hours) and be counted for 1.25 credits (4 semester hours).'
- *On gaining a view of engineering field and profession:* 'The interviews with different engineers helped me . . . The process of designing our own robot really helped me to see all the (design) options. The class showed me what engineering is all about . . .'
- *On skills development:* 'I went into this course with an interest in creating and designing useful tools. I definitely got quite a bit more. I learned how to program, design, solder, solve problems, accept defeat . . . All these lessons I learned are things I probably would not have learned if I hadn't taken this class.'
- *General comments:* 'A senior engineering major said to me that (the) 120 class has taught you more about real engineering than my four years here! I feel that I have learned an unbelievable amount and can't wait to take these 'basics' to the next level.'

TABLE 4 *Forms of participation in the robot contest (%)*

Forms	Fresh	Sophomore	Junior	Senior
Part of the course	76	14	33	29
Graduation project	0	0	40	43
Extracurricular activities	33	93	33	20
Hobby	29	43	20	24

Evaluation based on robot contest participation

Educational surveys were administered at the 1999–2001 fire-fighting contests at Trinity, to assess learning outcomes of contest-oriented curricula and attitudes of the participants. At each survey cycle the contestants were asked to complete new survey forms. An incremental survey method was applied in which each new survey cycle added knowledge to that previously found.

In 2001 answers were obtained from 243 respondents out of 407 registered for the contest, a better response than in 1999 and 2000 (respectively 112 and 123 respondents). Of those who responded to the 2001 survey, 94 were university students (39%), 90 were high school students (37%), 32 were middle school students (13%), 23 were working engineers (9%), and 4 were instructors (2%). Of the 94 university students, there were 21 freshmen, 15 sophomores, 15 juniors, 33 seniors, and 10 graduate (MS) students. The survey data were observed from different perspectives and were used to characterize learning outcomes for various categories of learners. We were interested in presenting statistical results for undergraduate university students in general and in analysing responses from the Trinity ENGR 120 students.

The 2001 survey questionnaire asked respondents first about the forms of their participation in the robot contest programme. They were asked to select from the following list: part of a course, graduation project, extracurricular activities, and hobby. The answers of undergraduate students in percentage are given in Table 4.

Differences between the groups of students were found:

- 1 The majority of first-year students participated in the contest as part of a formal course.
- 2 Sophomores participated mainly as an extracurricular or hobby activity.
- 3 Juniors were almost equally divided into those who participated in the contest as the graduation project, part of the course, or as an extracurricular activity.
- 4 For seniors the prevalent forms of participation were the graduation project (43%), and as part of a course (29%).
- 5 In most cases students combined participation as part of a curricular or extracurricular activity with involvement as a hobby.

Another section of the questionnaire asked each respondent to estimate his/her level of theoretical and practical knowledge in a number of subjects before he/she started to study robotics and his/her progress in the subjects due to robotics studies. The

TABLE 5 *Prior knowledge before taking ENGR 120*

Subject	1 (F)	2 (M)	3 (M)	4 (M)	5 (M)	6 (M)	7 (F)	8 (M)	9 (M)	10 (M)
Electronics	--	++	+–	+–	++	++	+–	–+	--	--
Computer communication	--	--	+–	--	--	+–	++	–+	++	--
Microprocessors	--	--	--	+–	--	--	+–	–+	--	--
Assembly language	+–	--	+–	--	+–	--	++	–+	++	--
High-level language	--	--	++	++	++	++	++	–+	–+	--
Motors and gears	++	++	+–	++	++	++	+–	–+	+–	++
Mechanical design	--	++	+–	--	++	++	+–	+–	--	++
Sensors	--	--	++	--	--	--	--	--	--	--
Data analysis	++	++	++	+–	--	--	++	+–	++	++
Physical fields	+–	++	+–	++	--	--	--	–+	--	++
Mathematical modelling	++	++	+–	+–	--	--	++	–+	++	--
Control	++	++	++	--	--	--	--	–+	--	--
CAD tools	+–	--	--	--	--	--	--	–+	--	--
Systems design	--	++	++	--	++	++	--	–+	--	--
Teamwork	++	++	++	+–	++	++	++	+–	++	++

answers that university students gave largely depended on their university department and year of studies. Background knowledge in the subjects varies significantly and deviates from average values even within the group of first-year students. To illustrate this conclusion, we consider the answers of ten first-year students in the Trinity ENGR 120 class (Table 5). The first column of Table 5 lists the 15 subjects. Each of the next 10 columns relates to one of the students. Symbols (M) and (F) in the top row designate male and female students. Two symbols ‘+’ or ‘–’ in a cell fitted in a row I and a column J mean presence or absence of theoretical and practical prior knowledge in subject I for student J.

Findings from the data in Table 5 include:

- 1 The students had heterogeneous background knowledge; almost all of them had no background in computer communication, microprocessors, sensors, control, systems design, or CAD.
- 2 Some students had no background in subjects that non-US students would likely encounter in high school physics and mathematics courses; such subjects include electronics, data analysis, physical fields, and mathematical modelling.
- 3 In many cases the students had only theoretical or only practical knowledge in the subjects.
- 4 No gender differences in prior knowledge were found.

The second part of this section of the questionnaire asked participants to estimate their advance in theoretical and practical knowledge in the subjects listed in Table 5 due to robotics studies. The answers given by the Trinity students are summarized in Table 6. The first and second columns of the table include numbers of students

TABLE 6 *Students advance in knowledge of subjects due to ENGR 120 (%)*

Theory	Practice	Subjects
100	100	Electronics, computer communication, motors and gears, mechanical design, control, sensors
90	100	Systems design
90	89	Microprocessor, high-level language
90	78	Mathematical modelling
80	89	Data analysis, teamwork practice
60	67	CAD tools
60	44	Physical fields
60	22	Assembly language

(percentage) who had advanced in theoretical and practical knowledge in the subjects listed in the third column.

Table 6 reveals the following:

- 1 The ENGR 120 course helped students to advance their knowledge in all 15 subjects.
- 2 All students on the course reported progress in electronics, computer communication, mechanical design, control, and systems design. A significant majority had made progress in microprocessors, CAD, high-level language, mathematical modelling, data analysis, and teamwork.
- 3 This progress took place in both theoretical and practical studies.
- 4 The average progress in practice in physical fields (44%) and assembly language (22%) is lower than in other fields.

The next section of the questionnaire related to personal activities in project-related subjects. The participants were asked to specify their personal involvement in designing, constructing, testing, and installing of each subsystem of the fire-fighting robot. The answers of the ten ENGR 120 students are presented in Table 7. Subsystems of the fire-fighting robot are listed in the first column of the table. Columns 2–11 describe activities of the ten students. Each cell in these columns includes some of letters d, c, t, and i, each of which designates a certain activity: d for designing, c for constructing, t for testing, and i for installing. A string 'dcti' fitted in a cell fitted in a row I and column J means that student J was involved in designing, constructing, testing, and installing of subsystem I.

Findings revealed by Table 7:

- 1 Every student in the group was involved in designing, constructing, testing and installing several robot subsystems.
- 2 Students work most actively on the drive mechanism, mechanical structure, sensor system, steering planning, and extinguishing device.
- 3 Students did not restrict responsibilities for robot subsystems between team-members but developed the subsystem together.

TABLE 7 *Involvement of ENGR students in developing robot subsystems*

Input to subsystems	1 (F)	2 (M)	3 (M)	4 (M)	5 (M)	6 (M)	7 (F)	8 (M)	9 (M)	10 (M)
Drive mechanism	dcti	dcti	dti	dcti	dcti	dcti	dt	dci	dti	dcti
Mechanical structure	dcti	dcti		dcti	dcti	dcti	ct	dcti	dcti	dcti
Micro-controller	ti	i		i	dcti	dcti	ti	ti	cti	
Control circuits	cti	cti		ti	dcti	dcti	ti	ti	dcti	
Sensor system	dcti	dcti	cti	dcti	dcti	dcti	dcti	dcti	dcti	cti
Steering planning	dcti	cti		dcti	dcti	dcti	dcti	dcti	dcti	cti
System software	dcti		dcti		dcti	cti	dcti	ti	dct	
Extinguishing device	ti	cti	i	cti	dcti	dcti	dcti	dcti	dct	cti

TABLE 8 *Motivation for participation in the robot contest programme*

Motivation factors	ENGR				
	120	Fresh	Sophomore	Junior	Senior
1. A positive attitude towards robotics and project-based learning	100	90	88	100	86
2. Awareness of the practical need for knowledge acquired through participation in the contest	70	74	88	100	75
3. Prizes, travel grants and other stimulation of your participation in the contest	10	11	0	31	14
4. Taking pleasure in robot gaming	60	58	63	88	31
5. Ambition to cope with the contest challenges and win a reward	40	47	56	75	61
6. Opportunity to develop and apply your own ideas	90	95	94	94	97
7. Interest in getting a high course grade	20	53	6	31	67
8. Demonstration of professional skills	50	53	63	75	77

4 The distinction between different types of activities was unclear to students 5 and 6.

The 2001 survey data on personal motivation for participation in the robot contest programme are summarized in Table 8. The motivation factors are listed in the first column of that table. The columns 2–6 present data about specific groups of respondents: the 10 first-year students from Trinity, and the whole groups of freshmen, sophomores, juniors and seniors. The number in each cell shows the percentage of respondents from a certain group who consider specific motivation factors important or very important to their participation in the contest.

Findings revealed by Table 8:

TABLE 9 *Attitudes towards robotics and engineering*

Attitudes	1 (F)	2 (M)	3 (M)	4 (M)	5 (M)	6 (M)	7 (F)	8 (M)	9 (M)	10 (M)
Interest in designing, building and operating robot systems	Lp	Lp	Sp	Sp	Sp	Sp	Sp	Sp	Sp	Sp
Interest in learning science and technology subjects	Sp	Lp	Lp	Sp	Sp	Sp	Lp	Sp	Lp	Lp
Interest in entering an advanced level engineering programme	Lp	No	Sp	Sp	Sp	Lp	Lp	Sp	Lp	No
Interest in specializing in robotics	Lp	Ng	Sp	Lp	Lp	Lp	Lp	No	Lp	No

- 1 A high level of learning motivation among all respondents.
- 2 Motivation is influenced by a combination of factors, each important to a certain sub-group of respondents.
- 3 Almost all undergraduate students mentioned the importance of the opportunity to apply their own ideas. A significant majority of them reported a positive attitude towards robotics and project-based learning.
- 4 Interest in getting a high course grade is more important for first-year and senior students than for sophomores and juniors.
- 5 All juniors and a significant majority of sophomores mentioned the practical need for knowledge acquired through participation in the contest.
- 6 Importance of the demonstration of professional skills grows as the students progress through their four undergraduate years.
- 7 Most undergraduate students do not consider prizes and travel grants as important motivational factors for their participation in the contest.
- 8 Motivation of the Trinity students was close to that of the whole group of first-year students, except the course grade factor, which was less important for them.

Table 9 presents attitudes of the ENGR 120 students about the contribution of the robotics studies to developing their interest in robotics and engineering. Four examined attitudes are listed in the first column of the table. The columns 2–11 describe attitudes of the ten first-year students. A code in each cell indicates the impact of the course on development of one of the attitudes by a certain student. Possible values of the code are: Sp for strong positive, Lp for limited positive, No for no contribution, and Ng for negative impact.

Table 9 indicates that:

- 1 All students answered that the course exerted a positive influence on their interest in developing robots and learning science and technology subjects. In this aspect the course completely achieved the goal. The answers of first-year students from Trinity agree completely with the corresponding results for all categories of respondents.
- 2 The majority of students (7 students) also mentioned the impact of the course on their interest in entering an advanced level engineering programme and in specializing in robotics. Students 2, 8, 10 did not develop an interest in specializing in robotics, and two of them did not indicate interest in further engineering studies.

Conclusions

Educational robotics relies on such core concepts of modern engineering education as constructionism, principal outcomes, and reflective practice. This paper presents a series of robotics courses at Trinity College as a continuous framework for integration of interdisciplinary connections, project assignments, and systems approaches throughout the engineering programme. The focus is on the introductory course ENGR 120.

Course assessment showed that ENGR 120 provided 'real' experiences to first-year students, exposed them to practical and philosophical dimensions of engineering design, engaged them in team-based cooperative learning projects, successfully addressed many basic ABET outcomes, and elicited a strong, positive student reaction. Concerns included improvement of the mentor programme, lack of formal credit for laboratory work, pressure of competition, and a wish for increased lecture time devoted to programming topics.

The course has not fallen short as a means to recruit engineering majors; of the total of 40 students who took ENGR 120 in 2000 and 2001, 20 enrolled in a sophomore-level engineering course the following semester. Trinity students declare their major fields at the end of the second year, so none are formally committed to Engineering when they take ENGR 120. The faculty view the first two years as a time for students to evaluate various fields as possible areas of concentration. The course seeks to inform students about the field and to motivate further study in it; but some will evaluate engineering through the course and choose a different major field. Enabling informed choices is viewed as a positive aspect of the course.

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