Assessing an Interdisciplinary Robotics Course

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1. Introduction

The curriculum in any specific area of study tends to narrowly focus students on that area, whereas real-world complex systems tend to integrate components from multiple disciplines. The development of such systems has shifted from designing individual components in isolation to working in cross-functional teams that encompass the variety of expertise needed to design an entire system.[2,8,15] This means that students must learn the team building and communication skills to work with others outside of their own discipline. The Accreditation Board for Engineering Technology (ABET) recognizes the importance of these abilities in its *Criteria for Accrediting Engineering Programs*: "Engineering programs must demonstrate that their graduates have an ability to function on multi-disciplinary teams".[1,5] The study of robotics provides an excellent instrument for teaching and learning about working in multidisciplinary teams.

The overall goal of this project is the development of a comprehensive undergraduate course in robotics that emphasizes multidisciplinary teamwork by encompassing many of the diverse fields of engineering which are integral to robotic systems: Computer Science (CS), Electrical and Computer Engineering (ECE), Mechanical Engineering (ME), and Industrial and Manufacturing Engineering (IME). This is a two-year project supported by a grant from the National Science Foundation's Division of Undergraduate Education under the Course, Curriculum, and Lab Initiative – Adaptation & Implementation Program. The course adapts curriculum material from CMU's General Robotics Course[2,14], from Swarthmore University's and Bryn Mawr College's Robot Building Laboratory Project (NSF CCLI Grant #9651472)[10], from Drexel University's Research and Education Tools for Low-Cost Robots (NSF CISE Grant #9986105)[6,7], from Bucknell University's Catalyst Team on Teamwork (NSF Grant #9972758)[8], and from Southern Illinois University Edwardsville's Laboratory Experience for Teaching Participatory Design (NSF CCLI Grant #9981088).[17]

This paper presents the outcome of the first offering of the course. The course is cross-listed for credit to students in each of these areas. It incorporates team-based robotics projects in which the teams are cross-functional and composed of one student from each area. For the first year, the course was taught by a team of faculty members from all of the represented areas. Emphasis was placed on cross-functional teamwork aspects, including the development of materials in each area as applied to robotics that was accessible to all of the students regardless of their majors and the development of robotics lab assignments that emphasized the multidisciplinary teamwork necessary for designing integrated systems. An eventual goal of the project is to produce course materials that would enable a single instructor to effectively teach the course to a multidisciplinary student body, with the possibility of occasional guest lectures from instructors in each discipline.

2. Course Organization and Teamwork

The course, entitled "Robotics: Integrated System Design", was offered for the first time in Spring 2004 as a senior-level elective in all four majors: CS, ECE, ME, & IME. Enrollment limits were used to achieve a balanced enrollment between the majors for the purpose of team formation. Twenty-nine students enrolled in the course: eight from CS, eleven from ME, and ten from ECE (six Electrical Engineers and four Computer Engineers). Following the guidelines put forth in "Practical Guide to Teamwork"[4], nine teams were formed using the criteria of major, availability, and grade point average. To ensure that teams were multidisciplinary, each team was assigned at least one student from CS, ME, and ECE (one team had a Computer Engineer in place of a Computer Scientist). The general topics covered in the course were:

- Control Theory: forward & reverse kinematics, feedback control
- Sensors: circuits and signal processing, simple computer vision
- Artificial Intelligence Control: localization, planning
- Multiple Robot Coordination

See Weinberg, White, et al.[18], for details of the course organization including team formation, grading, and a day-by-day schedule.

The topics were ordered using a layered abstraction approach[3], beginning at the lowest level of information, where relative position is used to determine movement (kinematics), proceeding to the attribute layer, where sensor input is processed to determine situations (behavior-based robotics), and finishing at the model layer, where abstractions of the world are used to make planning decisions.

Coverage of each topic area included some basic concepts of the respective discipline in order to provide students outside of that discipline with a sufficient framework for understanding the more advanced concepts. To mitigate the potential for disinterest and boredom caused by presenting basic concepts to students within their respective discipline, concepts were covered from the perspective of their application to robotics.

The choice of robotics platforms for the team lab assignments and projects included LEGO mechanical pieces and the Handy Board Controller (www.handyboard.com).[11] This platform was chosen for its mechanical flexibility, its ability easily interface with custom-built sensors, the availability of a C development environment (IC: Interactive C), and the availability of a low-cost color camera, the CMUcam (www-2.cs.cmu.edu/~cmucam/). Robot kits developed by the KISS Institute for Practical Robotics were purchased (www.kipr.org), and each kit included a vast amount of LEGO pieces, geared and servo motors, a variety of pre-built sensors, a CMUcam, a Handy Board, and a LEGO Robot Controller (LEGO RCX). In addition to the robot kits, electronic parts were purchased for labs that required the development of custom sensors as discussed in Section 3.

3. Hands-on Laboratory Assignments

The lab assignments provide an opportunity to directly interact with the technology, as well as an opportunity to design, implement, and experiment with the various concepts that they embrace. This approach to teaching creates an active learning environment in which students can explore a significant design area, make hypotheses about how things work, and conduct experiments to validate their assumptions.[9,12,13,16] Seymour Papert termed this style of learning “constructionism”.[16] For this course, the overall philosophy of the lab assignments is to provide a hands-on, multidisciplinary design experience that complements the lecture material. In this way, it creates a type of “directed constructionism” learning experience in which students are asked to explore related topics in a specific order.[13,15]

3.1. Lab Assignment 1: Rube Goldberg Machine

The first lab assignment was a team-building exercise that involved the design and implementation of a Rube Goldberg Machine (See www.rgmc.com) that would capture a mouse without harming it (see Figure 1). The machine was required to consist of at least five energy transfers (steps). The students were allowed to use only the non-electronic parts from their robotics kits. However, teams were permitted to add other materials, with the exception of batteries or power supplies. The main intention behind this lab was to provide students with an opportunity to participate in a fun activity while moving through the early stages of team formation. The secondary expectation of this lab was to familiarize the students, particularly the ME team members, with the mechanical parts of the robot kits.

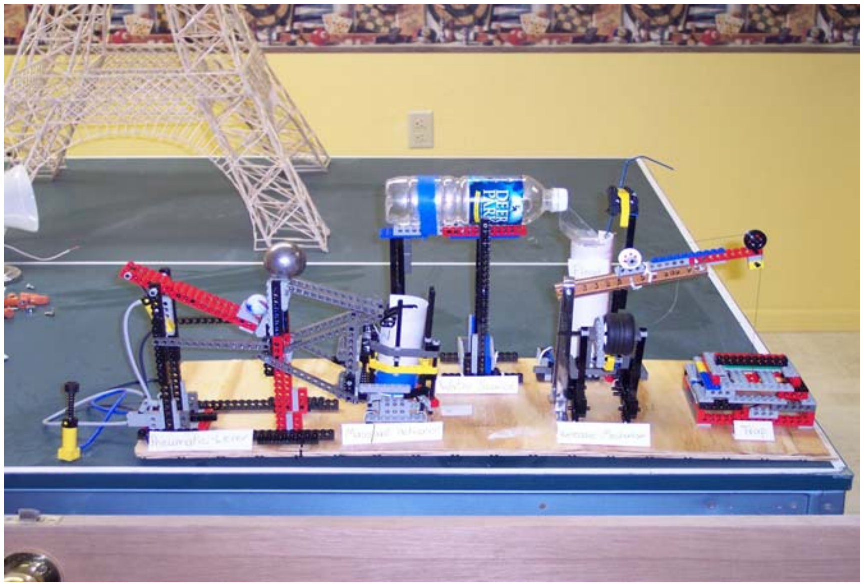

Figure 1: A Rube Goldberg Machine Using Pneumatics and Hydraulics

3.2 Lab Assignment 2: Mobile Bug Behavior

The second assignment was designed to help students learn about the electronics components of their kits as well as giving them the chance to practice with the IC4 programming environment. The assignment involved simulating a bug behavior (see Figure 2). One goal of this lab was to provide a team experience on an integrated system that includes mechanics, electronics, and computation.

The objective was to build a mobile bug that would “wake up” when exposed to a strong light. The bug was then supposed to scan the area in front of it for the closest object, which it would interpret as a food source. The bug would use the sonar sensor placed on a turret mechanism to accomplish this task. The turret would turn by means of a servo motor. Once the bug identified the closest object, it would be expected to move in the direction of the object. Using touch sensors as “antennae”, the bug would find the food and stop to “feed”. It was the first lab assignment that incorporated a component of all three disciplines: ECE team members determined the characteristics of the sensors, assisting CS team members to understand how to interpret the input. ME team members designed the mobile base, the turret, and antennae, and assisted CS team members in programming the controls for the bug’s searching behavior.

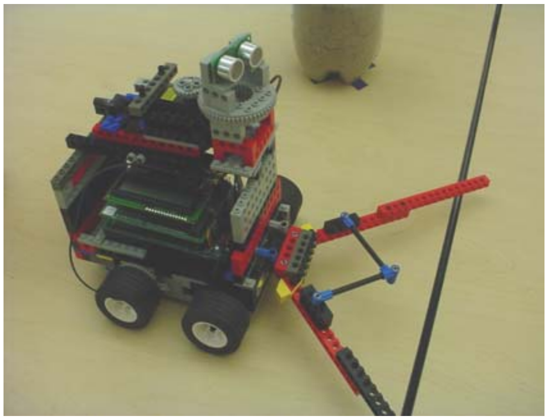

Figure 2: A Bug with Sonar Sensor

3.3 Lab Assignment 3: Homing Light Sensor

The third assignment concerned sensor electronics and was designed to provide additional integrated system experience in mechanics, electronics, and computation. It required the design and fabrication of a custom light sensor for use with the Handy Board that could "home in" on a light source (see Figure 3). The light sensor was to differentiate between detecting the source on the left or right sides so the robot could determine which way to move.

The goal area was defined as the set of all points in the working plane within six inches of the light source. The light source consisted of a small light bulb located in the center of the circle. The robot was required to remain "quiet" until the light source was activated, whereupon the robot was expected to "home in" on the source as quickly as possible.

ECE team members designed and implemented the light sensor, and instructed CS team members concerning the interpretation of the input. ME team members designed the mobile base and instructed CS team members concerning how to control it.

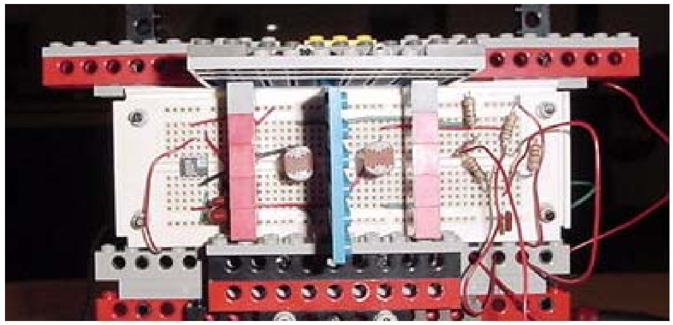

Figure 3: Student Implementation of a Custom Light Sensor

3.4 Lab Assignment 4: Robotic Arm

The fourth assignment involved the design of a two-link manipulator robotic arm that would accurately track a one-inch-radius circular closed path with its tip (see Figure 5). The center of the circle was located at world coordinates (0, 6) and the tip motion was required to quickly trace out the circle in a counter-clockwise direction, starting and ending at coordinates (1, 6). The implementation of a Derivative Proportional (DP) closed-loop control was required to achieve the desired accuracy. Two rotational potentiometers were required to be used to sense the joint angles.

ME team members designed the manipulator, developed the kinematics solutions for control, and helped CS team members implement the DP control. ECE team members designed the angle sensors from the potentiometers and aided CS team members in interpreting the input from these sensors.

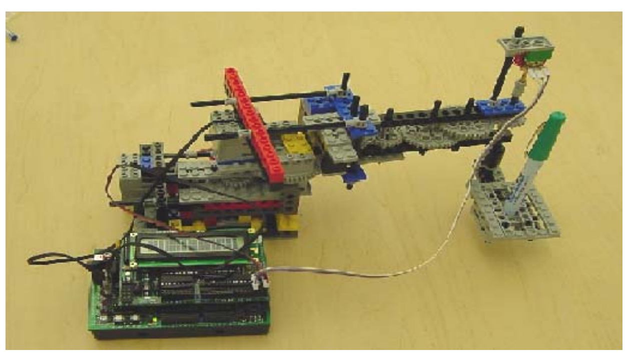

Figure 4: A Two-Link Robotic Arm

3.5 Culminating Project: Autonomous Urban Search & Rescue Robot

The objective of the project was to design and implement an autonomous search and rescue robot for an earthquake-damaged building, using the back story detailed in Figure 5.

An earthquake registering 7.5 on the Richter scale along the New Madrid Fault has caused extensive damage across Missouri, Southern Illinois, and Tennessee. An emergency response team was sent out to search for potential victims in a warehouse near I-255, which has suffered severe damage in part of its storage facility.

In the midst of their heroic efforts to find and save factory workers, an aftershock measuring a 5.3 on the Richter scale hits and 7 emergency workers, scattered throughout the factory, are too badly injured to escape. Rescue workers have asked that your Robotic Rescue Team dispatch a robot to help identify where the workers are trapped so that critical resources can be focused on the rescue of the emergency workers.

The local rescue workers have provided you information about the warehouse that you might find useful for your robot. They have provided a blueprint of the area needed to be searched as well as photos of the facility prior to the earthquake. Your team has been given 25 minutes to search the facility for the rescue workers.

Figure 5: The Urban Search & Rescue Back Story

The goals of the project were:

- To have each team design and implement an autonomous search and rescue robot.
- To have each team design and implement a custom sensor for sound localization.
- To have each team explore methods of localization.
- To have each team design and implement an algorithm for autonomous navigation.

The search area was a 10’x10’ area with various obstacles, divided into five rooms with a sixth room located in an upper level that was only accessible by means of a ramp with a 30-degree grade. The robot’s mission was to locate all victims wearing uniforms of a specific color, as well as a victim that was “screaming for help” (see Figure 6). The screaming victim was a sound source generating a 2 kHz tone. An additional sound source generating a low tone at 200 Hz was placed in the arena as a “non-victim” sound to determine whether the sensor design was accurately distinguishing the victim sound source. When a victim was detected, the robot was supposed to approach the victim, set off a series of beeps, and record the exact location of the victim in a two-dimensional array. The array representing a floor map was downloaded after the robot’s run to check for accuracy.

Figure 6: An Urban Search & Rescue Robot Finding a Victim

4. Assessment and Evaluation

In addition to the four course instructors, a fifth faculty member was designated to conduct activities designed to assess the success of the course in meeting its goals with respect to multidisciplinary teamwork. The assessor attended the lectures and project presentations, and oversaw the implementation of numerous assessment tools that were designed to gauge the effectiveness of various aspects of the course. The principal assessment tools are listed below, in the order in which they were administered.

1.	**Pre-Course Survey** • This survey was used to gauge the background of the students in CS, ECE, IME, and ME, as well as to help determine team membership. • The students were asked to specify their majors, their course background in all three disciplines (CS, ECE, and ME), their experience with teamwork, and the times that they would be available for team meetings. • Students were asked basic questions from each discipline, that majors should already know, to determine the extent of non-majors' comprehension. These technical questions would reappear on the Final Exam to gauge the effectiveness of the cross-disciplinary instruction.
2.	**Term Quizzes** • Each Term Quiz was designed to contain some questions that were specifically designed to measure the understanding of non-majors (i.e., questions that students within the discipline would be expected to know prior to the course, but that students outside the discipline would not be expected to know prior to the course).
3.	**Mid-Point Questionnaire** • Approximately halfway through the course the students were given a non-technical questionnaire with bulleted questions and essay questions regarding their opinions regarding the course's cross-disciplinary effectiveness.
4.	**Discipline-Specific Discussion Sessions** • About two-thirds of the way through the course, informal sessions with the assessor were scheduled, in which students in each of the CS, ECE, and ME disciplines discussed their concerns about the course and the cross-disciplinary problems they were encountering (if any). These interview sessions included discussions about team efforts up to that point in the course.
5.	**Peer Reviews of Cross-Disciplinary Teams** • Just prior to the final project presentations, students filled out peer review forms for their teammates, emphasizing the effectiveness of the cross-disciplinary aspects of the course's preparation, the effectiveness of their teammates at representing their respective disciplines, and their effectiveness at representing their own discipline within their teams.
6.	**Project Final Reports** • At the end of the semester, each team submitted a final report regarding the project, including a "post-mortem" of what went wrong and what went right. This report included significant feedback on the effectiveness of the multidisciplinary teamwork, as well as suggestions for how this aspect of the course might be improved.
7.	**Post-Presentation Interviews of Cross-Disciplinary Teams** • Within a few days of each team's project presentation at the end of the course, the team met with the assessor to review the cross-disciplinary aspects of the project and the course as a whole.
8.	**Final Exam** • The Final Exam contained several of the technical questions that appeared on the initial Pre-Course Survey, which were used to contrast non-majors' understanding of other disciplines before and after the course. • Additional questions were included on the Final Exam that required the students to make connections between two of more of the course disciplines.
9.	**Course Evaluations** • Additional bubble questions were added to the school's standard Course Evaluation Forms to query the students regarding the effectiveness of the multidisciplinary aspects of the course. Students were also encouraged to provide constructive criticism on the form's essay questions concerning the course.

Table 1: Cross-Disciplinary Assessment Tools

An analysis of the results of administering these assessment tools provides some insight into the degree to which the course succeeded in its goals of multidisciplinary teamwork and cross-functional learning. These insights are summarized in the following subsections.

4.1 Assessment of Multidisciplinary Teamwork

The Peer Reviews (Mechanism #5 from the list) and the Team Interviews (Mechanism #7) were specifically designed to facilitate the assessment of the extent to which the course successfully provided students with effective experiences within multidisciplinary teams.

Peer Reviews

On the Peer Reviews, students were asked to use a four-point scale to evaluate their teammates with respect to four desired attributes: commitment, cooperation, motivation, and participation. The cross-disciplinary results are displayed in the tables below.

Commitment		**Evaluated Teammate**		
		CS	**ECE**	**ME**
Evaluator	**CS**	NA	3.0	3.1
	ECE	3.3	3.0	2.7
	ME	3.5	3.3	4.0

Cooperation		**Evaluated Teammate**		
		CS	**ECE**	**ME**
Evaluator	**CS**	NA	3.3	2.8
	ECE	3.0	3.0	2.8
	ME	3.6	3.2	4.0

Motivation		**Evaluated Teammate**		
		CS	**ECE**	**ME**
Evaluator	**CS**	NA	3.0	3.1
	ECE	3.0	3.0	2.5
	ME	3.4	3.3	4.0

Participation		**Evaluated Teammate**		
		CS	**ECE**	**ME**
Evaluator	**CS**	NA	2.6	3.1
	ECE	3.4	3.0	2.6
	ME	3.8	3.3	4.0

4=Extremely High; 3=High; 2=Average; 1=Low; 0=Extremely Low

Table 2: Cross-Disciplinary Peer Evaluation Results

Of particular interest in these numbers are the cross-disciplinary asymmetries, in which students from two disciplines perceive each other as having significantly different levels of certain desired attributes. For instance, while CS and ECE students evaluated each other as comparable in terms of commitment, cooperation, and motivation, the ECE students perceived their CS teammates as substantially more active participants than the CS students perceived the ECE students.

Similarly, CS and ME students considered each other comparable in terms of commitment and motivation, but ME students viewed their CS teammates as having higher levels of cooperation and participation than the CS teammates viewed the ME students.

The widest disparity between disciplines in these peer evaluations was between the ECE and ME students, with the ME students considered slightly less cooperative and substantially less committed, motivated, and participatory.

Written comments on the peer evaluation forms tended to display recognition of the contributions of each discipline. ECE and ME students acknowledged how essential it was to have a CS teammate who could design flexible algorithms, and quickly code and debug their implementation. ME and CS students commented upon the critical contributions that ECE students made to circuit design and sensor modifications. Finally, ME students were recognized by their CS and ECE teammates for bringing specific structural and mechanical knowledge to those projects that particularly needed them (i.e., the robotic arm and search-and-rescue projects).

As expected, personalities and different work ethics frequently affected mutual perceptions in the peer evaluations. Common complaints included apathy, procrastination, closed-mindedness, and chronic unavailability. Such comments were far outnumbered by complimentary remarks, however, emphasizing helpfulness, creativity, organization, experience, and pragmatism.

Team Interviews

Each project team met with the course assessor within a few days of demonstrating its search-and-rescue final project, to discuss the course's emphasis upon teamwork, and to suggest improvements that might be made to the projects in future versions of the course. In the presence of the entire team, individual team members tended to downplay personality conflicts and praise each other's efforts on the projects. However, many teams voiced the opinion that each project should be easily divisible into equal CS, ECE, and ME components, or, alternatively, that preliminary projects should take turns in focusing on particular disciplines, with the final project composed of three comparable, distinguishable parts.

Most of the other comments from students during these team interviews concentrated upon the relative lack of time allocated to some assigned projects, with particular emphasis placed upon the inadequate amount of time provided to design and implement the final search-and-rescue project. A specific recommendation of several teams was to enhance the quality of the final project by designing the earlier lab assignments to serve as components of the final project.

4.2 Assessment of Cross-Functional Learning

Assessment mechanisms designed to gauge the course's success in imparting cross-functional learning included the Pre-Course Survey (Mechanism #1 from the list), the Term Quizzes (Mechanism #2), the Mid-Point Questionnaire (Mechanism #3), the Discipline-Specific Discussions (Mechanism #4) and the Final Exam (Mechanism #8).

Mid-Point Questionnaire

Conducted halfway through the course, the Mid-Point Questionnaire queried the students regarding their background in their own and their teammates' disciplines, as well as the extent to which they and their teammates were contributing to team understanding of the course projects. The results of this survey are summarized in the tables below.

Background In Each Discipline		**Evaluated Discipline**		
		CS	**ECE**	**ME**
Evaluator	**CS**	3.5	2.8	1.7
	ECE	2.9	4.0	2.3
	ME	2.3	2.8	3.0

4=Extremely Prepared
3=Reasonably Prepared
2=Insufficiently Prepared
1=Unprepared

Contribution To Team Understanding		**Team Member's Discipline**		
		CS	**ECE**	**ME**
Evaluator	**CS**	3.3	3.0	2.8
	ECE	3.3	3.2	2.9
	ME	3.8	3.6	3.2

4=Indispensable Contribution
3=Significant Contribution
2=Negligible Contribution
1=Negative Or No Contribution

Table 3: Cross-Disciplinary Mid-Point Questionnaire Results

While students from each discipline expressed confidence in their preparation in their own discipline, CS students felt very unprepared for ME material, while ECE students felt somewhat weak in ME and ME students felt rather weak in CS. These perceived shortcomings were rather effectively addressed, however, with ME students evaluated as contributing significantly to their CS and ECE teammates' understanding of the ME discipline's role in the assignments, and CS students evaluated as contributing tremendously to their ME teammates' understanding of the CS discipline's role in the assignments.

Discipline-Specific Discussions

The course assessor conducted open discussion sessions with the students from each of the three disciplines about two-thirds of the way through the course, concentrating on any cross-disciplinary problems that had been perceived by the students. While all three groups expressed favorable impressions of the course as a whole, a common theme in these discussions was the perception that the CS students were rather overburdened in the projects, while the ME students often had little to contribute. CS students saw themselves as "project closers", who were forced to fix last-minute problems with both the ECE and ME portions of the lab assignments. ECE and ME students agreed that their lack of programming experience made it impossible for them to contribute significantly during the latter stages of the assignments. On the other hand, the overwhelming consensus, even among the ME students, was that the early assignments contained negligible ME components, resulting in the ME students feeling rather useless for most of the course. Most students from each discipline advocated a more equitable distribution of the assignment workload across the three disciplines.

Term Quizzes

Term quizzes were administered in each of the four disciplines involved in the robotics course, and each discipline's quiz contained some questions that were designed to help assess the success of cross-functional instruction in the course. Each discipline's instructor designed some questions in such a manner that students from that discipline (who had completed discipline-specific course prerequisites) were expected to know the associated course material before taking the robotics course, while students from other disciplines were not. The performance on the quiz questions is shown in Table 4.

Question Discipline & Topic	CS Students	ECE Students	ME Students	Total
CS: Finite-State Machines	83%	71%	64%	71%
CS: Breadth-First Search	88%	72%	82%	80%
CS: Algorithm Complexity	68%	76%	46%	62%
ECE: Resistors	35%	82%	64%	62%
ECE: Capacitors	88%	98%	96%	94%
ECE: Inverting Gain Amplifiers	63%	64%	45%	57%
ECE: Non-Inverting Gain Amplifiers	93%	97%	96%	96%
IME: Gear Ratios	90%	75%	94%	86%
ME: Transform Matrices	28%	28%	45%	34%
ME: Forward Kinematics	69%	85%	66%	73%
ME: Inverse Kinematics	53%	45%	64%	54%

Table 4: Student Performance on Discipline-Specific Quiz Questions

While students in a particular discipline unsurprisingly tended to perform better on quiz questions from their own disciplines, it is notable that the gap between the mean performance of students from a particular discipline and the mean score of all of the students in the course was usually quite narrow. Each discipline's quiz contained one question with which another discipline's students had difficulty (i.e., ME students performed 16% below the mean for the CS question on algorithm complexity; CS students performed 20% below the mean for the ECE question on resistors; and ECE students performed 9% below the mean for the ME question on inverse kinematics).

On the other hand, the ECE numbers provide several unexpected insights. ECE students outperformed CS students on the CS question concerning algorithm complexity and their scores on the ME question on forward kinematics far exceeded those of the ME students. Interestingly, the ECE students performed comparatively poorly on the IME question about gear ratios, in spite of the fact that ECE and ME students are required to take the same IME course, while CS majors have no IME course requirements.

Pre-Course Survey and Final Exam

A primary mechanism for measuring the cross-functional learning that occurred in this course was the administration of an ungraded pre-course survey on the first day of the course and a graded final exam on the last day of the course, containing equivalent questions from the disciplines of CS, ECE, and ME. The pre-course survey, which also contained questions regarding previous courses, experience with teams, and time availability outside of class, was ostensibly administered to assess student background and to help formulate project teams. The students were not informed that the survey's technical questions would also appear on the final exam, and the surveys were not returned to the students.

The nature of the questions from each discipline and the comparative averages from each discipline's students are displayed in the table below.

		CS Students		ECE Students		ME Students		Total	
		Survey	Exam	Survey	Exam	Survey	Exam	Survey	Exam
Question Discipline & Topic	CS: Binary Trees	88%	90%	10%	68%	0%	76%	29%	77%
	CS: Heuristics	13%	100%	10%	85%	0%	77%	7%	86%
	CS: Finite-State Machines	50%	100%	32%	84%	0%	81%	26%	87%
	CS: Algorithm Complexity	88%	100%	8%	98%	0%	84%	28%	93%
	ECE: Resistance	45%	82%	84%	87%	52%	85%	61%	85%
	ECE: Operational Amplifiers	0%	59%	68%	91%	12%	64%	29%	72%
	ME: Rigid Bodies	0%	60%	28%	57%	66%	82%	34%	67%
	ME: Gear Ratios	75%	71%	40%	60%	80%	76%	64%	69%
	ME: Force & Torque	33%	83%	50%	90%	86%	100%	58%	92%

Table 5: Comparison of Pre-Course Survey and Final Exam Results

As expected, on the pre-course survey, students performed reasonably well on questions from their own discipline and they performed somewhat better on those questions on the final exam. (A more substantial improvement was demonstrated by CS students on the questions relating to heuristics and finite-state machines, topics not always covered in the CS prerequisites to the robotics course.)

Cross-functional improvement was much more pronounced, with substantial improvements in ECE and ME scores by non-majors, and vast improvements in CS scores by ECE and ME students. An analysis of the academic backgrounds of the students in this course provides a satisfactory explanation for this disparity. CS and ECE students frequently take calculus and physics courses, in which certain introductory ME topics are introduced. Similarly, CS and ME students usually take beginning circuits courses, in which resistors are commonly studied. However, the introductory programming courses to which most ECE and ME students are limited usually do not cover the more advanced CS topics included on the pre-course survey and final exam.

4.3 Assessment of Course and Projects

The Project Final Reports (Mechanism #6 from the list) and the Course Evaluations (Mechanism #9) were designed to provide an overall assessment of the effectiveness of the course, and to solicit suggestions from the students regarding improvements that might be attempted in future versions of the course.

Project Final Reports

Each team of students submitted a final report on its search-and-rescue project, which included a "post-mortem" describing the successful and unsuccessful aspects of the team's project and its collaborative efforts as a whole. Teams commonly cited the lack of time for this project (three weeks at the end of the semester) as the principal difficulty, with several standard obstructions to teamwork (i.e., difficulty in establishing meeting times, diverse levels of engagement, insufficient up-front planning, and personality conflicts) also mentioned.

The post-mortem documents recognized the value of interdisciplinary projects and identified the gain of mutual respect for each other's disciplines as one of the course's primary benefits. The spirit of cooperation in most teams appeared to be quite high, and the opportunity of gaining experience with "experts" from other fields was frequently specified as one of the main benefits of taking the course.

Course Evaluations

At the conclusion of the course, the students were asked to evaluate the course and the instructors via anonymous questionnaires that included essay questions regarding how the course might be improved. The most common comment from students regarded the perceived imbalance between the workloads of the team members from different disciplines. Students from all three disciplines perceived ME as the area that was least utilized in the projects. Coincidentally, the presented lecture material that was seen as least relevant to the projects was ME, which was considered to be presented in too much depth, both by non-ME students and by ME students.

While several students expressed confusion at the four-instructor approach, by and large, students praised the course for providing hands-on experience with practical projects, using teams of contributors from multiple disciplines. Complaints concerning the demands that the course made on the students' time were common, but the majority of the students expressed no regrets about having taken the course, as well as strong positive feelings regarding the benefits of having done so. A number of students from each discipline expressed the opinion that this course provided them with the most practical experience of any course thus far in their college careers.

5. Future Work and Enhancements

The multidisciplinary robotics design course will be taught again in Spring 2005. The assignments and course material shall be altered to reflect the student feedback and instructor perceptions of what did and did not succeed in the pilot version of the course.

5.1 Lab Assignment Restructuring

A common complaint from students in the pilot version of the robotics course was the perception that the preliminary lab assignments failed to adequately prepare the teams for the culminating search-and-rescue project. Many teams reported having difficulty adjusting to the volume of new skills needed on this final project, including camera operation, sound localization, and navigational mapping. A strong consensus was reached among both students and instructors that a more progressive, modular approach to the lab assignments would be more appropriate in the next version of the course, rather than the discipline-centered assignment approach taken in this first version. A comparison of the two approaches is illustrated below.

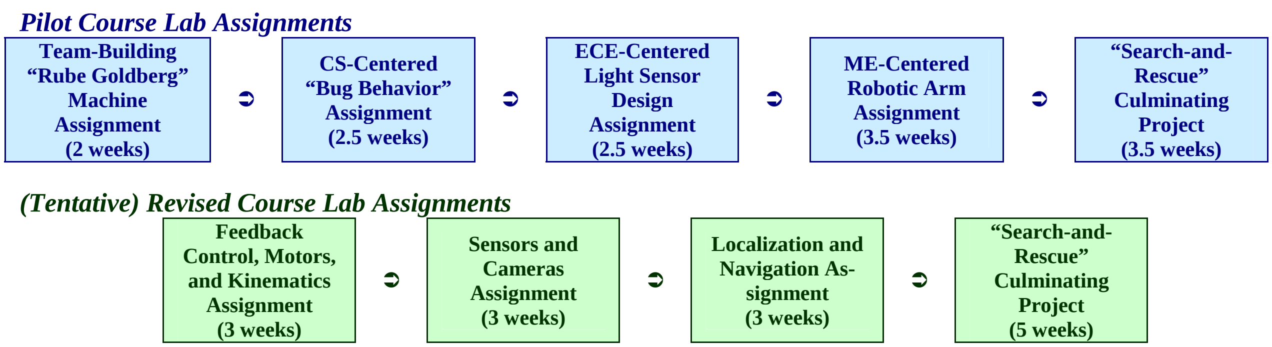

Figure 7: Lab Assignment Progression in Pilot and Revised Versions of the Course

This revision also addresses two other problems with the lab assignments that were cited by students and instructors. First, the pilot version's initial "team-building" assignment was viewed by many as being unnecessary, due to the advanced academic rank of the students and their previous experience with team-oriented projects within their respective disciplines. By changing the initial lab assignment to focus on long-range course goals that should be reasonably accessible early in the term, the process of team-building should be achieved in a more productive manner.

Second, the reduction of lab assignments from five to four should address the commonly voiced problem of inadequate time for the more advanced assignments. In the pilot version of the course, teams were allocated 2 to 3.5 weeks to complete each lab assignment, with only 3.5 weeks allocated to the culminating search-and-rescue project. Under the revised plan, the first three assignments will be allocated three weeks apiece, with five weeks set aside for the culminating project. This will provide teams with adequate time to develop superior designs, as well as to fully test their implementations.

In addition to this anticipated restructuring of the lab assignments, students have expressed a desire for more competitive contests between teams in the course. Demonstrations of the search-and-rescue culminating projects in the pilot version of the course were conducted in a public arena, with dozens of student spectators and extensive local media coverage. This fact proved quite motivating for students, and many indicated that such good-natured competition, even without any impact on grades, provided teams with additional an incentive to excel on the assignments. As a result, the inclusion of head-to-head demos, perhaps with web-posted results, is being considered for the next version of the course.

5.2 Improved Team Management

Perhaps the most counterproductive characteristic of many team efforts in the pilot version of the course was the tendency to “pipeline” the lab assignments, i.e., awaiting the full implementation of prerequisite components of the assignment before proceeding with the design and implementation of later components. This problem usually took the form of CS students failing to construct the software framework for an assigned robotics application until their ECE and ME counterparts completed the implementation of their respective parts of the assignment. This practice often resulted in the last-minute discovery of fundamental design flaws and, consequently, the rushed implementation of only partial functionality.

To encourage teams to better manage their lab assignments, the revised version of this course will require each team to submit an initial design document early in the development process for each assignment (e.g., within the first week of each three- or five-week cycle). These documents will be quickly evaluated, assessing the practicality of the design, the equity of the workload distribution among team members, and the appropriateness of the test plan. With at least half of the allocated time for each assignment still available, it is expected that this practice will alleviate the pipelining problem and improve the overall quality of each team’s submitted assignments.

5.3 Reduction in Actively Participating Faculty

The NSF support obtained for this project provided the resources to permit four faculty members to directly participate in course instruction for the pilot version of the course, one each from CS, ECE, IME, and ME. While occasional guest lectures are certainly possible from instructors from each discipline in future incarnations of the course, one of the project’s goals has been to produce course materials that would enable a single instructor to effectively teach the course to a multidisciplinary student body.

In the Spring 2005 version of the course, the set of instructors will be reduced from four to two. The CS and IME instructors will continue to be directly involved with course instruction, making use of the course materials (and possible guest appearances) of the ECE and ME instructors. The refinement of the course notes and assignments from this next version are expected to produce a body of instructional materials (including the possibility of a multidisciplinary robotics textbook) that will facilitate this course being conducted by instructors from any one of these disciplines in the near future.

5.4 Dissemination of Course Material

The current course materials for the integrated systems design course in robotics are available on-line at http://www.cs.siue.edu/robotics/integratedsystems/. The second iteration of the course will begin in January 2005, with an ensuing report on its effectiveness and the insights afforded by the project expected to follow in Summer 2005.

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