Project Description

1 Introduction

In this proposal, we design the next generation robot laboratory. We have conquered LEGO robot instruction, and now we are ready to look beyond it. This step is a difficult one, since higher level robots have been designed for research, not for classroom use. In addition, we want to make this laboratory accessible to as wide a range of instructors and students as possible. We especially want to include those that normally are precluded from state-of-the-art research. In order to accomplish these complex goals, we have designed an approach to combine the development of the hardware, software, and curriculum.

Project-based learning can be an effective learning method. In a pilot program that compared a project based introductory programming course to a traditionally lectured course, most of the project students "felt they were engaged in meaningful learning. In addition, whereas only 5 percent of the PBL class found the course overwhelming, over 30 percent of the matched-CS1 class found themselves in this category. The PBL class had most students indicating that they felt positive about the course, whereas the matched-CS1 class had the majority of students indicating that they felt either bored or anxious about the course" [Greening et al 1997, p. 204]. They also found that the course developed several skills, including problem solving, group work, software development, report writing, verbal skills in computer science and testing of programs.

The expected outcomes of the proposed work are as follows:

- Full development of innovative materials for teaching project-based robotics modules in a variety of computer science courses based on a prototype developed at Bryn Mawr College
- Multiple assessments of the effectiveness of the materials at different types of institutions serving students with diverse backgrounds and career goals. Longitudinal studies will be performed to assess the long-term affects of the curriculum on the students and faculty.
- We have 8 faculty members at 6 test sites who are prepared to use the materials in Fall 2003. We will be recruiting 8 to 10 additional schools in each of Years 2 and 3 to implement the curriculum in their schools. This will result in a test set of 22 to 26 schools over three years.
- Dissemination of information about the developed materials through a web site, conference papers and presentations, and publication of a textbook.
- Self-sustaining national distribution through the web site archives and discussion groups, as well as the textbook distribution by its publisher.[1]

2 Results from Prior NSF Support

Deepak Kumar and Lisa Meeden were awarded a two year NSF ILI-IP grant starting in 1996 in the amount of $58,000 for a proposal entitled "A robot laboratory for teaching artificial intelligence."[2] The objective of this project was to improve the

[1] Publisher is still to be determined. Talks have already occurred with acquisitions editors at Prentice Hall and MIT Press. Both were interested in the book, although no formal agreements have been made.
[2] Award Number: NSF ILI-IP 9651472

instruction of undergraduate AI courses by providing a unifying theme based on simple, LEGO-based robots with Handyboard controllers. Each topic in AI was presented as a robot task. Students then built their own robots and programmed them to accomplish these tasks.

As a result of this grant, curricular materials were developed and integrated into undergraduate courses taught at Bryn Mawr College and Swarthmore College [Kumar 1998, Kumar and Meeden 1998a, Kumar and Meeden 1998b]. Furthermore, a resource kit of laboratory materials was prepared and distributed as part of the dissemination component to enable other schools to adapt materials that developed for the project [Kumar and Meeden, 1998c]. Kumar and Meeden have documented at least 50 faculty members who have used these materials to create similar laboratories at their own institutions.

3 Goals and Objectives

The LEGO-based robot has served undergraduate faculty well for the last five years. Since the curriculum development by Kumar and Meeden, the Handyboard controller has been redesigned as a mass market consumer product called LEGO Mindstorms. These developments have enabled the introduction of LEGO-based robots into middle schools, high schools, and even elementary schools [for example, see the Kiss Institute's Botball competition at www.kipr.org]. Because of this, more and more incoming undergraduate students are already quite knowledgeable about basic robotics concepts and are ready to delve more deeply into research-level questions.

The more advanced robots we are proposing to use now are quite similar to those used in various state-of-the-art robot deployments such as Mars rovers, museum tour guides, and hazardous landscape exploration. However, in introducing these more advanced robots into our own courses we have found that they can be difficult and intimidating for undergraduates to use. This is mostly due to the fact that the robots are primarily marketed for high-level research or industrial deployment and there isn't sufficient usable documentation and software for novices.

We propose to change the way that topics in Artificial Intelligence are taught by developing software and curriculum for a wide variety of project modules (described in Section 4.3). The project-based modules can be used as an independent course or integrated into other courses (see Section 4.3 for a discussion of an independent course using the modules and Appendix A for examples of how the modules could be integrated into existing courses).

Our goal is to make research-level robotics hardware and methodologies accessible to computer science faculty who may not have robotics experience and to their undergraduate students. Due to past successes with project-based learning, we believe is that undergraduate students who are engaged by research-level projects of this kind will be more likely to do well in the rest of their computer science studies and, ultimately, to attend graduate school. We will track the grades, attitudes, and career paths of students who take courses using our curriculum and to compare them to other students graduating with computer science degrees from the same institutions who have not been exposed to our curriculum to assess the success of the project in meeting our objectives.

4 Detailed Project Plan

We look to accomplish our objectives by building a series of modules and then mentoring interested faculty at other institutions. We will provide these faculty with a solid foundation for introducing research-level robotics by recommending a robot platform that is more advanced than the Handyboard and a simulator with good user support, by providing a software system designed for experimenting with a wide range of more complex robot controllers, and by introducing a curriculum integrated with the robot platform and software system that could be used in a variety of courses.

Mentored faculty will be encouraged to submit CCLI-A&I proposals in order to obtain the recommended robot hardware. However, many of the materials we will provide can be used with a robot simulator alone.[3] In addition, a number of faculty interested in participating in this project have already acquired some of the recommended hardware, but have not yet been able to introduce it effectively into their courses (for example, see the attached letters of intent from Bowdoin and Bloomsburg University).

Our project proposes the integration of three key components to creating the next generation robot laboratory: a hardware platform, a software platform, and a curriculum. In the next sections, each of these components will be described in detail.

4.1 Hardware Platform: The Pioneer 2 Robot

Kurt Konolige designed the Pioneer robot about seven years ago as a small research platform that could be used for advanced robotics classes. The technology has

[3] While many of the modules can be done in simulation, students will benefit more from using the robot hardware. Interaction with the world can be simulated, but not fully realized. The simulator will be unable to run the vision module. Additionally, without the robot hardware, project opportunities during and after the course will be lost. We believe that students will have a much richer project experience through the use of the hardware.

been licensed to ActivMedia, allowing other faculty to buy the robots and use them for teaching and research. The robot hardware is very reliable and robust, making it an excellent choice for a classroom situation. According to ActivMedia, there are 1,000 Pioneer robots (I and II) in the field. Of these robots, only 10 are sent in for repair each year.

The configuration that we are proposing for this work includes an embedded computer, a front and rear sonar array (used for obstacle detection and mapping), a gripper mounted to the front of the robot (used to create more interesting lab scenarios, allowing the systems to include manipulation in addition to mobility), a single camera pan-tilt-zoom head (used for mobility, planning and teaching students vision algorithms), wireless Ethernet (used for programming and controlling the robot from a remote computer, either in the lab or across the internet, and for multi-robot communication), and a rear bumper.

In addition to supporting our modules well, this robot configuration allows the robot to be used for student research projects that go beyond the course materials.

4.2 Software Platform: Pyro

Pyro stands for Python Robotics. The purpose of the Pyro software is to provide a stable, integrated, environment that can be used for experimenting with robot controllers on several robot platforms as well as simulators. Currently, the robots supported include: the Pioneer family (Pioneer and Pioneer 2 robots) and the Khepera family (Khepera and Khepera 2 robots). There are also two simulators available, both of which simulate the Pioneer family of robots.

Pyro has the ability to define different styles of controllers. For example, the control system could be a neural network, a subsumption architecture, a collection of fuzzy logic behaviors, or a symbolic planner. Any program that controls the robot (physical or simulated) is referred to as the brain. It is written in Python and usually involves extending existing class libraries.

The libraries help simplify robot specific features and provide insulation from the lowest level details concerning hardware drivers. In fact, the abstraction provided uniformly accommodates the use of actual physical robots or their simulations even though vastly different drivers and communication protocols may be used underneath the abstraction layer. Consequently, a robot experimenter can concentrate on the behavior-level details of the robot. Robots may feature a disparate set of sensors and movements, and yet, depending on the specific robots or simulators used, Pyro provides a uniform way of accessing those features without getting bogged down by low-level details.

Pyro also provides facilities for visualization of various aspects of a robot experiment. Users can easily extend the visualization facilities by providing additional Python code as needed in a particular experiment. For example, you can easily create a graph to plot some aspect of a brain with just a few lines of code.

In picking a development language for our project pilot at Bryn Mawr, we were faced with a series of constraints: we wanted a system that was easy for beginning students to learn, provided a modern, object-oriented paradigm, would run on many platforms, would allow exploration of many different control paradigms and methodologies, would remain useful as users gained expertise, could be easily extended, and allowed for creating modern-looking visualizations.

First, we examined existing projects to see if any fit our constraints. There are many open sourced robotics programming environments available; however, most are committed to a particular control strategy. Separating the control strategy code from the rest of the system code seemed to require a major rewrite in all cases that we examined.

However, Teambots is one open source project that satisfied many of our goals [Balch 1998]. Teambots is written in Java, and, therefore, is object-oriented. However, because security is of such importance in Java, there are some additional burdens placed on the programmer. For example, multiple inheritance must be implemented through single inheritance combined with interfaces. Although Sun has been developing a standard 3D programming interface for Java, Teambots has not yet taken advantage of this interface.

We decided to build a prototype using the extensible modeling language XML and C++ [Blank 1999]. Although this system had some nice qualities derived from its XML roots, it turned out to have all the complexities of XML and C++ combined, and was therefore difficult for introductory students to learn.

Having learned from our first prototype, we decided to build another, but this time to focus on the usability from the perspective of the new user. We found that the language Python meets many of our goals. Python is an object-oriented, interpreted language that recently has been used as an introductory programming language, as well as for solving real-world complex programming problems. For example, [Prechelt 2000] found in some specific searching and string-processing tests that Python was better than Java in terms of run-time and memory consumption, and not much worse than C or C++.

Python has a fairly clean object and inheritance syntax that supports multiple inheritance. It also has bindings to TCL and OpenGL, two mature graphics APIs for 2D and 3D drawing, respectively.

Pyro was designed so that all aspects of the robot control could be studied, and altered, by non-experts. For example, we have implemented most of the Saphira fuzzy logic behavior engine in 200 lines of Python code.

Pyro was successfully used in the Spring 2002 semester in the Bryn Mawr College course "Androids: Design and Practice." Two of the students from that course have been awarded summer interships to continue the development of Pyro. The proporsed curriculum developed for this grant and described in the next section is based on the material covered in this Androids course. Due to its past success, we plan to adapt these materials for use in other schools.

4.3 Curriculum: Project-oriented modules

The curriculum has been divided into a collection of largely independent modules. These modules could be used in the order given to outline a single course, or could be used piecemeal to supplement other courses. The first two modules, which introduce the Pyro software and basic robot control concepts, should be used prior to any other module. Each module will have related exercises, reading materials, and software support.

Module 1: Introduction

This module provides an overview to using the Pyro system. Topics include: starting up the software, connecting to a simulator, connecting to a robot, using existing robot controllers, and learning the basics of the python programming language. An on-line Pyro tutorial, developed for the prototype at Bryn Mawr, can be found at http://emergent.brynmawr.edu/wiki/index.cgi/PyroTutorial.

Module 2: Reactive Control

This module introduces the student to the most simple robot controllers, starting with Braitenberg vehicles [Braitenberg 1984] which connect motor responses directly to sensor inputs. Topics include: understanding sensor responses (light, infrared, sonar, and bump), understanding actuator behavior (differential drive and gripper), recognizing the problem of noise in the real world, and learning to tightly couple sensors and actuators for effective real-time control (see, for example, [Flynn and Brooks 1989]).

Module 3: Behavior-Based Control

This module discusses the idea of behavior-based robotics control [Arkin 1998]. Two main methodologies are explored: subsumption architecture [Brooks 1986], and a more general approach using fuzzy logic [Saffiotti, Ruspini, and Konolige 1993]. Topics include: behavior design, multi-tasking, motor and perceptual schema, fuzzy logic, finite state autonoma, and creating behaviors for obstacle avoidance, picking up trash, and going to specific locations.

Module 4: Vision

This module explores visual processing for mobile robots. The main focus is integrating vision as a sensor in robotics tasks (see, for example, [Konolige 1997] and [Briggs et al 2000]). Topics include: vision algorithms (edge detection, blob detection, filters, convolution, optic flow, color histograms), and using vision algorithms to locate an object by color or by shape, detect motion, track motion, identify people.

Module 5: Planning and Reasoning

This module will focus on the deliberative aspects of mobile robotics. Graph search methodologies and logic form the foundation of this module [Stentz 1994, Stentz 1995, Konolige 2000]. Topics include: first-order logic, state-space diagrams, and various search methods such as A*.

Module 6: Learning

This module will explore robot adaptation. Two major paradigms are explored: neural networks and evolutionary computation [Meeden 1996, Meeden and Kumar 1998]. Topics include: designing appropriate tasks, neural networks architectures and learning methods, genetic algorithms, combining neural networks and genetic algorithms, and adapting solutions to tasks that were previously engineered.

Module 7: Mapping and Localization

This module explores issues in creating and following topological and spatial maps [Martin and Moravec 1996, Gutmann et al 1998, Konolige and Chou 1999, Gutmann and Konolige 2000, Thrun 2002]. Topics include: building a map, following a map, localization, occupancy grids, and probabilistic states.

Module 8: Multi-Agent Robotics

This module will explore coordination and communication issues in multi-agent robotics. At least two robots will be required to implement this module outside of the simulator. Topics include: emulating behaviors of groups of animals, building a shared map of a space, coordinated behavior to solve problems that a single robot could not accomplish, and communication methods. ([Balch and Parker 2002] contains a large number of relevant papers in this field and [Yanco 1994] specifically addresses communication issues.)

4.4 Pilot Schools

In Year 1, the modules will be tested at a variety of school types:

- Bloomsburg University is a four-year co-educational public university which has graduate degree programs (but not in Computer Science). It has approximately 7,000 undergraduates and 700 graduate students. There are 7-8 FTE committed to CS classes in the Department of Mathematics, Computer Science and Statistics.
- Bowdoin is a private liberal arts institution with approximately 1,600 undergraduate students. The Computer Science Department graduates about 15

majors or minors each year. The department has 4 tenure track faculty, but are staffed for leaves, equating to 3 FTEs.

- Bryn Mawr is a private women's college with approximately 1,300 undergraduates. (Bryn Mawr has a co-ed graduate program with approximately 400 graduate students, but there is no graduate computer science program.) The Computer Science Department graduates an average of 3 majors and 2 minors each year. The department has recently increased to 3 FTEs and expects to increase its graduations to 8-12 majors and 4-6 minors each year soon.
- Stanford is a private university with 6,400 undergraduates and 7,500 graduate students. Stanford offers BS, MS, and PhD degrees in Computer Science. The Computer Science Department graduates 100-150 undergraduates, 100-150 master's students, and 5-10 doctoral students each year. The department has approximately 41 faculty members.
- Swarthmore is a private college of liberal arts and engineering with approximately 1,375 undergraduate students. The Computer Science Department graduates an average of 25 majors and minors each year. The department has 4 tenure track faculty with about 5 FTEs counting adjuncts.
- UMass Lowell, one of five campuses of the University of Massachusetts, has 6,000 undergraduates, 4,000 continuing education students, and 2,500 graduate students. UMass Lowell offers BS, MS and ScD degrees in Computer Science. The Computer Science Department graduates about 60 undergraduates, 55 master's students, and 5 doctoral students on average each year. With recent hires, the department will have 20 FTEs in Fall 2003 and 21 FTEs in Spring 2003.

The schools represented in our first year pilot are small and large, co-ed and single sex, public and private, undergraduate only or with graduate program, and liberal arts colleges and large universities.

The pilot classes will be targeted to undergraduate students. However, we will also test the materials in a graduate robotics class at UMass Lowell, starting in Spring 2003.

In Years 2 and 3, we plan to expand our pilot program to include additional schools. In Year 2, each of the PIs will mentor one or two new schools, adding eight to ten colleges and universities to the pilot program. We plan to recruit these Year 2 schools in Year 1 through a wide variety of methods including a chairs mailing, the SIGCSE e-mail list, the AAAI e-mail list, and personal contact. These schools will be encouraged to apply for the DUE CCLI A&I grant in November 2003, which will bring them on board for Summer 2004 to get them ready to teach the course in Fall 2004. We will recruit again in Year 2 for Year 3, adding another eight to ten schools to our pilot.

4.5 Workshops

We will run three workshops for faculty who will be teaching courses using our materials. The workshops will be one week long, held during the summer. In these workshops, we will discuss the curriculum and will teach the faculty how to set up, use, and program the robots. We want to support faculty without robotics experience in their use of the robots to engage their students in the material; the workshops will be used to assist them with getting up to speed.

The first workshop will be held at UMass Lowell in the summer of 2003. The second and third workshops will be held in conjunction with AAAI's National

Conference on Artificial Intelligence in order to expose non-robotics faculty to additional robotics research demonstrated at the annual AAAI Robot Competition and Exhibition. Holding the workshop at the AAAI conference will also allow us to bring together students and faculty from the prior year's pilot classes together with the new faculty learning about the course for the next year. Finally, we hope to encourage faculty to pursue projects with their students after the course ends, and we plan to suggest the AAAI Robot Competition and Exhibition as a possible project path for students.

Workshop materials will be archived on our curriculum web site, providing access to faculty outside the pilot program who wish to implement the materials. We will also maintain a discussion group web site where we will encourage faculty from the pilot program to help support new faculty who are adapting the curriculum for their schools.

4.6 Mentoring

Our goal is to include a variety of colleges and universities in our pilot program, which will allow us to test the materials in many different situations. Senior faculty who do research in robotics at a large university are likely to have different experiences than computer science faculty at a small college which has never had a robotics class. To support the novices, we plan to provide mentoring for the schools in our pilot program.

The five PIs will each support one or two schools during our Year 2 and Year 3 in the fall semester rollout of the materials. This support will include being available for phone calls and e-mail to answer questions about the robots and the materials. All PIs will have at least one robot in the same configuration as the robots purchased by participating schools with funding from their CCLI-A&I grants. This hardware will allow us to offer remote support when a faculty member sends us their code or explains what they are trying to do.

In addition to providing remote support, mentors will travel to their schools at least once during the semester to meet with the faculty and students. We plan to offer to act as a guest lecturer and also to give a research talk to expose the students to robotics research. We also would like to rotate the mentors to other schools, so that each school gets a visit from two different PIs. This will require each mentor to make at most four trips in the fall semester (two to their schools, two to other schools).

Mentoring will begin at the workshop and continue throughout the school year. We will encourage faculty to teach the course during the fall semester, when we have planned the mentoring activities described above. In the spring semester, mentors will visit two other schools, providing each school with an additional research talk in robotics. During the spring, we will encourage the students from the fall semester to work on projects for the AAAI Robot Competition and Exhibition. (Of course, schools may choose to teach the course in the spring semester, but this limits project possibilities and only exposes seniors to one semester of research talks from visiting mentors.)

At the completion of this three year project, we will have created a community that will be available to informally mentor others who want to adapt the materials for use in their school. A discussion board on the web site will be used for current discussions and to archive past discussions.

4.7 Continued Project Work

We will encourage faculty to teach the course in the fall semester, leaving open the option of independent project work for the students in the spring semester. Students who are interested in robotics will then have the chance to do larger projects on a platform with which they are already very familiar. However, unstructured project time is likely to be unsuccessful for some students. To solve this problem, we are planning to encourage the students to develop systems for the AAAI Robot Competition and Exhibition. Each year, the competition lays out several events with specific rules to guide the development process. More independent students could choose to create a system for the exhibition, which encourages a wide variety of demonstrations.

To bring together the prior year's pilot schools with the new batch of schools, we plan to hold the workshops in Years 2 and 3 at the AAAI's National Conference on Artificial Intelligence held in the summer, usually at the end of July.

5 Experience and Capability of the Principal Investigators

The course will be developed by five AI/Robotics researchers at different types of schools. The team has expertise with developing the robot hardware to be used in the course, with developing widely distributed courses through NSF's CCLI program, and with organizing the AAAI Robot Competition and Exhibition. All teams members have taught at least one robotics and artificial intelligence course during their academic careers.

Holly Yanco is an Assistant Professor in the Computer Science Department at the University of Massachusetts Lowell. She has many years teaching experience at MIT, Wellesley College, Boston College, and ArsDigita University. While a graduate student at MIT, Holly was invited to teach recitation sections for MIT's flagship introductory course (Structure and Interpretation of Computer Programs), which is a position normally reserved for faculty members. In 1996, she was awarded the Hennie Teaching Award by the EECS department at MIT. In 2002, she was awarded a Teaching Excellence Award by UMass Lowell. She has developed course materials for a wide variety of classes, including Artificial Intelligence, Robotics, Introduction to Computer Science for Non-Majors, and C Programming. She is active in outreach activities to middle and high school students, chairing the Massachusetts Botball committee and running other teacher workshops. In 1997, she chaired the AAAI Robot Exhibition. In 2001 and 2002, she co-chaired the AAAI Robot Competition and Exhibition. Holly's research addresses the problems of shared control between robots and people in applications such as assistive robotics and urban search and rescue.

Douglas Blank is an Assistant Professor in the Math and Computer Science Department at Bryn Mawr College in Philadelphia. He received a joint Ph.D. from Indiana University in Cognitive Science and Computer Science in 1997. Doug has developed and taught a wide range of courses for majors and non-majors in computer science, including "Androids: Design and Practice" and "Robots Gone Berserk: A Look at Robots in Film". He has been active in Boosting Engineering, Science, and Technology (B.E.S.T.), a program designed to get high school students interested in those topics by building remote controlled robots. He has been involved in the AAAI Robot Competition, as a participant and organizer. His competition teams have won two Technical Achievement Awards there. Doug's current research interests include creating neural network models of analogy-making, and building the new field of developmental robotics.

Deepak Kumar is an Associate Professor of Computer Science at Bryn Mawr College. He received his PhD from The State University on New York at Buffalo based on work on the design of rational agent architectures in Artificial Intelligence. Since 1993, he has been developing a new computer science program at Bryn Mawr College. The program has since evolved to 3 FTEs, and is continuing to grow. Several innovative curricular improvements have been incorporated by him and have also become models for adaptation at other institutions. In 1995, along with Lisa Meeden of Swarthmore College, he introduced the use of small robots in the undergraduate curriculum. He has carried out several outreach activities for Philadelphia-area public schools designed to introduce school teachers to the latest developments in technology and worked on mentor programs to encourage students from deprived school districts to enroll at Bryn Mawr for higher education. His research interests in Artificial Intelligence include intelligent robotics, cognitive robotics, robot learning, and more recently developmental robotics. He has served on several international program committees of research and educational conferences.

Lisa Meeden is an Associate Professor in the Computer Science Department at Swarthmore College. In graduate school at Indiana University, she received an award for Outstanding Associate Instructor. In 2001 at Swarthmore College, she received the Lindback Award for excellence in teaching. She has served as an instructor at the NSF sponsored summer faculty enhancement workshops on teaching undergraduate artificial intelligence in 1995, 1996, and 1997. She has developed course materials for a wide range of courses, including artificial intelligence, robotics, and several seminars on computational models as well as introductory CS courses such as data structures, object-oriented programming in Java, imperative programming in C, and functional programming in Scheme. She has co-led winning Swarthmore student teams at the AAAI robot competitions in 1999 and 2000. Her research is currently focused on creating developmental architectures for adaptive robots.

Kurt Konolige is a Senior Computer Scientist at the Artificial Intelligence Center of SRI International, a Consulting Professor of Computer Science at Stanford University, and a Fellow of AAAI. He received his PhD in Computer Science from Stanford University in 1984. His recent research has concentrated on real time perception and navigation for mobile robots. He teaches a course in mobile robotics at Stanford University, and co-developed the Pioneer and AmigoBot robot line and the Saphira robot control architecture. Relevant recent projects where he serves as PI include visual mapping for the Army Combined Technology Alliance robotics effort; navigation and perception for the NASA Personal Satellite Assistant project; mapping, environment reconstruction, and navigation for the DARPA Tactical Mobile Robotics project; a lunar rover navigation project for Nissan Aerospace; and design of robotics navigation and perception software for commercial robotic vehicles. He has been an invited lecturer at universities and institutions in many different countries, and is or has been on the editorial board of various academic publications, including Fundamenta Informaticae, Journal of Applied Non-Classical Logics, International Journal of Applied Intelligence, Artificial Intelligence Journal, and the Journal of Artificial Intelligence Research. He has authored over 100 scientific publications, including 3 books and Best Papers at the 1995

IJCAI conference and the 1998 IROS conference. He is a co-founder of ActivMedia Robotics.

In addition to their individual experience, several of the team members have collaborated with each other before. Lisa Meeden and Deepak Kumar collaborated in the design of the robot lab course described in Section 2. Kurt Konolige and Holly Yanco are both consulting on a project to design a robotic wheelchair with ActivMedia. All of the PIs have worked together for the AAAI Robot Competition and Exhibition.

6 Evaluation Plan

We plan to use several evaluation methods to inform the revision of our modules and study the impact of our curriculum, as described in [Frechtling 2002]. During the initial years of the curriculum development, formative evaluations of the modules from the perspective of the faculty and students at the pilot schools will be conducted. The formative evaluations of the curriculum will be used to update the materials throughout the three year grant period. Additionally, we will track students throughout the proposal period to create a summative evaluation to measure the the impact of the course upon the student's performance in subsequent computer science classes and career choice post-graduation. A summative evaluation of the faculty will be performed to measure the number of faculty who continue to use course modules, the software and the hardware beyond their participation in the initial pilot semester.

There are several opportunities to track the faculty members who participate in the pilot program each year. The pre-workshop questionnaire will ask the faculty why they are participating in the program, what they expect to learn from the workshop, how they expect the course might change their teaching style, and what prior teaching experience they have had with a variety of courses from programming to robotics. The post-workshop study will focus on how the workshop was taught, asking questions that will guide the redesign of the workshop for later years. Before the course starts, we will ask the faculty members which modules they plan to use during the school year and in what course, how much preparation time they have invested in the course so far, what additional materials they might have read (if any), planned course hours, and how many students have preregistered for the course. During the course, we will ask the faculty members to fill out post-module surveys immediately after they complete each module, in addition to cataloging all e-mail contact with questions and comments about the materials. A sample post-module faculty survey is shown in Appendix B. At the end of the course, the faculty will be asked to reflect upon the past semester, answering questions such as the number of students completing the course, how they taught the course (number of exams, which modules were actually used, how many class meetings there were each week, the length of lab periods (if any)), and their thoughts on how the students perceived the course.

Students will be surveyed at the start of the course, immediately after each module, and at the end of the course. So that we may track student comments across the semester, each student will be assigned a number to put on their surveys. Pre-course surveys will ask for the students' prior programming experience and other CS courses they have taken, what they expect from the course, and ask if they have any robotics experience. A sample post-module student survey is shown in Appendix B; the survey would be adapted for the specific contents of the module. Finally, a post-course survey will be used to ask the students their opinions on the course and how to change it. In this survey, we will attempt to separate the students' feelings about the faculty member from their feelings about the course materials.

With the faculty, we can track problems with the materials by cataloging their e-mails. However, we will not have this direct interaction with the students. To provide us with a more complete tracking of the student experiences with the materials, we plan to encourage the faculty to have their students maintain a course notebook, as suggested in [Scherz and Polak 1999]. The student notebook will allow completed materials to be collected, while providing a place for students to record their thoughts about the course. We will ask for student notebooks to be photocopied and sent to us for evaluation. Faculty could also choose to maintain a notebook, which would keep track of their lecture and lab preparations, other readings, and intra-module thoughts about the course.

We will also create two web forums: one for the faculty teaching the course at different schools and one for the students at the different schools to talk amongst themselves. Both will be archived for study. (In the web forum, people will be able to choose a nickname, bringing them anonymity.) UMass Lowell already has a server running web forums, which we can use for this purpose.

After the course has ended, we plan to ask the faculty to help us track the students in a longitudinal study to determine if the project course has an effect upon their grades in later classes or their career choice. We have hypothesized that a project class which engages students will motivate them in other computer science courses; anecdotally, we have seen students become engaged by a robotics class, resulting in great improvement in their overall school performance. By measuring student grades in computer science preclass and post-class, we will be able to judge if our class has engaged students sufficiently to improve their performance in later classes. Additionally, we have seen that students who participate in robotics projects, particularly projects outside of class such as the AAAI Robot Competition and Exhibition, tend to attend graduate school at a greater rate than those who do not. For example, at Swarthmore College, of the 18 students who have participated in the AAAI Robot Competition since 1997, eight students have gone on to do graduate work in artificial intelligence or robotics at Carnegie Mellon University, Georgia Institute of Technology, Purdue University, University of Edinburgh, University of Massachusetts at Amherst, and University of Michigan. A longitudinal study of students as they graduate will allow us to test this hypothesis; the control group will be the other graduating computer science majors in the school who did not take the course. We recognize that a self-selected group of students may take the robotics course, so we will also use historical data of graduate school attendance from each school, if it exists.

Summative evaluations will be done to answer the questions of how the course impacts the grades and career paths of the students and if the modules are reused by the faculty in later semesters.

7 Dissemination of Results

We have several dissemination methods planned for our curriculum, including pilot schools, a web site with materials and discussion boards, and publishing a textbook.

Throughout the project period, the materials will be tested in undergraduate classes at the home institutions of the PIs (Bryn Mawr, Stanford, Swarthmore and UMass

Lowell). Additionally, the materials will be tested with graduate students at UMass Lowell.

We will use pilot schools in all three years for testing the materials. We have tried to select a variety of schools in the home institutions of the PIs and our two Year 1 pilot schools (Bowdoin and Bloomsburg University). In Years 2 and 3, we will recruit an additional eight to ten schools, again attempting to reach a broad variety of schools so that the materials may be tested in many different situations.

Materials developed will be distributed via a web site to be hosted at UMass Lowell. We have budgeted funds to pay an undergraduate student to design and maintain our web site during the project period, allowing us to ensure that it will be kept up-to-date with curriculum and software updates. This web site will also host discussion groups for the faculty and students participating in our pilot program; UMass Lowell already has software that will enable these discussion boards. The discussions will be archived for adaption into FAQs.

After the project period ends, the discussion boards will remain on the site to offer informal mentoring between faculty who have already adapted the class and faculty who wish to adapt the class for their institution. All materials will remain on the web site for distribution.

We are also investigating the possibility of publishing a textbook that use the developed materials as its basis. There is currently no textbook in the market that teaches project-based robotics for high level platforms. We have already had conversations with acquisition editors at Prentice Hall and MIT Press, both of whom were interested in discussing the matter further. We will have a draft of this text completed between Years 2 and 3.

We plan to write papers about the curriculum, its development and the evaluation studies for conferences such as SIGSCE and will also look to publish in education related journals.

8 Timeline

Year 1 (1/1/2003 – 12/31/2003):

Spring 2003: Initial development of course: lecture notes, assignments, software, projects, robot set up guide
Initial course modules to be tested at UMass Lowell
Recruit schools for Year 2

Summer 2003: Full development of course modules
Workshop for professors from pilot schools to be held at UMass Lowell

Fall 2003: Course to be taught at non-PI pilot schools (Bowdoin and Bloomsburg) and co-PI schools
Year 2 pilot schools apply for CCLI-A&I grants

Throughout year: Evaluation of assessment materials used to redesign course materials

Year 2 (1/1/2004 – 12/31/2004):

Spring 2004: Full course to be tested at UMass Lowell
Independent project work at pilot schools
Recruit schools for Year 3

Summer 2004: Evaluation of assessment materials used to redesign course materials
Lecture notes from modules refined into more of a textbook format
Workshop at AAAI-2004 for ten Year 2 pilot schools
Year 1 pilot schools bring robots to AAAI Robot Competition and Exhibition

Fall 2004: Course to be taught at ten Year 2 pilot schools and schools from Year 1 pilot
Year 3 pilot schools apply for CCLI-A&I grants

Year 3 (1/1/2005 – 12/31/2005):

Spring 2005: Full course to be tested at UMass Lowell
Independent project work at participating schools

Summer 2005: Evaluation of assessment materials used to redesign course materials
Workshop at AAAI-2005 for ten Year 3 pilot schools

Year 1 and 2 pilot schools bring project work to AAAI Competition and Exhibition

Fall 2004: Course to be taught at ten Year 3 pilot schools and schools from Years 1 and 2
Summative longitudinal studies
Publication of textbook

9 Conclusion

We are proposing the full development of an innovative curriculum for the next generation robotics laboratory, which has already been prototyped at Bryn Mawr. By moving to research robots from Handyboards and Lego, we will be teaching technology that is currently used in robotics research to undergraduates. This will enable students to participate in research projects, giving them an out of class educational experience.

We plan to recruit our pilot schools from a diverse set of institutions, with two pilot schools in Year 1, eight to ten more schools in Year 2, and eight to ten additional schools in Year 3. The course will also be taught at the four institutions represented by the PIs.

We plan to make multiple assessments of the effectiveness of the materials at different types of institutions serving students with diverse backgrounds and career goals. Longitudinal studies will be performed to assess the long-term affects of the curriculum on the students and faculty.

We will disseminate information about the developed materials through a web site, conference papers and presentations, and publication of a textbook. There will be self-sustaining national distribution through the web site archives and discussion groups, as well as the distribution of the textbook by its publisher.