Using Mobile Robots to Teach Artificial Intelligence Research Skills

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Abstract

Successful Artificial Intelligence researchers must be able to think creatively and critically, communicate effectively and evaluate the results of their work. Therefore, it is important that we include courses in our curriculum that develop these skills. Since one usually learns best by doing, we believe a project-based course, in which students receive hands-on experience, will be most effective in fostering quality research skills. We also wanted a project that would be fun and exciting, appeal to a wide range of students and allow for explorations in a range of AI topics. We felt that the area of mobile robotics would make an ideal match. The field of mobile robots provides a challenging and exciting arena for developing, applying and evaluating AI techniques. While there are many benefits to incorporating mobile robots into the classroom, starting a mobile robot lab can seem like a daunting, time-consuming task with a steep learning curve and expensive price tag. This is not necessarily the case. The mobile robot lab we describe in this paper was developed in a short time period with relatively little cost, yet it is proving to be a valuable teaching tool. In this paper we describe the design of the course and how mobile robots are used to meet the course objectives of surveying advanced AI concepts and teaching research skills. We evaluate the advantages and disadvantages of using mobile robots that we have observed, including feedback received from students during the semester.

1 Introduction

Being a successful researcher requires a variety of skills including the ability to think creatively and effectively, evaluate work, schedule time and communicate effectively in proposals, reports and presentations. Therefore, it is important that our graduate courses not only provide knowledge of advanced topics, but also help students develop these research skills. We also believe that students learn best through doing. Therefore, we felt a project-based course in which students participated in a small research project would be appropriate. With this in mind, we have designed a graduate course in artificial intelligence that is intended to introduce students to some advanced topics in AI and give them first-hand experience in many aspects of a research project. As part of the project, students design and evaluate a system, write a proposal and report and present their results to the rest of the class.

We had several factors in mind when deciding on a topic for the project. We wanted a project that would allow students to apply the knowledge they learn in class while allowing for creative solutions. We also wanted the project to be fun for the students and encourage class discussion. Inspired by success stories with the use of mobile robots at schools such as MIT [5], Case Western Reserve University [2], and Trinity College [1], we felt that the field of mobile robots would be an ideal match for our objectives. Mobile robots provide a challenging and exciting arena for developing, applying and evaluating AI techniques. Situated in the world, mobile robots must deal with issues of uncertainty, reliability and real-time response [4]. They must be capable of integrating sensing and planning to produce an appropriate course of action and, ideally, they should learn from their experiences. Mobile robots are also fun to work with and expose students to new technology.

Although there are many advantages for using mobile robots in the classroom, there are also some potential drawbacks. The time and cost of starting a new mobile robot lab for students may appear to be prohibitive. It may be over-ambitious to expect students, who may not have prior experience with electronics, to learn about robotics, assemble a robot and carry out a significant research project within a semester. Students may become overwhelmed.

In this paper we describe a graduate course in AI that uses mobile robots to teach AI research skills. The mobile robot lab was developed in a relatively short time and with a low cost, yet has served as an effective educational tool. We discuss some advantages and disadvantages of using mobile robots from our experience and share feedback from our students on how they perceived the use of mobile robots.

2 Course Objectives

The Advanced Artificial Intelligence class is a graduate course in artificial intelligence offered in the Fall of each year at Vanderbilt University. The course assumes that the students have taken an introductory AI course, or are familiar with the area. There are two main objectives of the course. First, the course serves as a followup to the introductory AI course, providing a survey of more advanced topics in AI. Second, the course is intended to introduce students to performing research in AI. As such, our goal is to teach AI concepts along with basic research skills.

Meeting the first objective, providing a survey of advanced topics in AI, requires a certain balance between breadth and depth. Because AI is such a large and diverse field, we would like to expose students to a wide range of topics. However, because it is an advanced course and we want the students to focus on a project, we also want to explore topics in depth. In the past two years a trade-off has been made in favor of depth. A small set of related topics have been selected and explored in detail. The theme for the class over the last two years has been planning and learning. This seems to be a good choice as these two areas are central to much of AI and are highly compatible; one of the primary emphases is on learning to improve planning. An additional advantage is that the primary interests of the AI faculty in the department are in these areas so we can bring our personal research experiences into the class.

The second objective, introducing students to AI research, is met by having the students conduct a semester-long research project. A challenge is posed that relates to the topics in the class and students must devise a solution. To solve the challenge, students can adapt an approach discussed in class, choose a technique discussed in related literature or come up with something on their own.

3 Course Design

To meet the above objectives, the course has two main components: textbook and research paper readings and the class project. Typically, the textbook is used to introduce a new concept or approach and then this is followed up with research papers. To facilitate class discussion and encourage critical thinking, students are asked to write reaction papers for each research paper reading. In these reaction papers, they describe what they liked and did not like about the reading and make suggestions for how they think the work could be extended.

The project extends throughout the course and is intended to give students first-hand experience in conducting a research project. To give students the full flavor of what research is like, the project includes many aspects of a typical research project including proposal and report writing, design and evaluation and presentation of results.

We decided to use mobile robots as the focus of the class project. Of course, other topics could support the course objectives. In fact, the previous year in which this course was taught in this manner, students worked on extending a classical AI planner and did not use robots. We felt, however, that mobile robots offered unique advantages. Because mobile robots are situated in the world, they offer important challenges for AI. The robots must deal with uncertainty in sensors and actuators, perform robustly in a wide range of situations and respond in real-time in a dynamic environment. Mobile robots provide a physical system to experiment with, helping make many of the abstract ideas in AI more concrete for the students. Using mobile robots has an additional benefit of introducing students to an important technology that is taking on a larger role in our lives.

We decided to allow students to work in small teams on the project. This decision was based on a number of factors. First, we anticipated that working with robots would be new to most students. Working in a group would provide an environment where students would be able to help each other learn about mobile robots. Similarly, a group structure will allow students to bounce ideas off one another. Second, research, especially AI research, is becoming increasingly multi-disciplinary and it is important that students be able to function effectively in a team. Finally, having students work in teams reduces the number of robots required, thereby reducing the overall cost of supporting the course. While this should not be a driving factor, it is, nevertheless a real concern. It was not an issue for us this year as we ended up with an extra robot because students preferred to work with more team-members rather than break off into smaller groups.

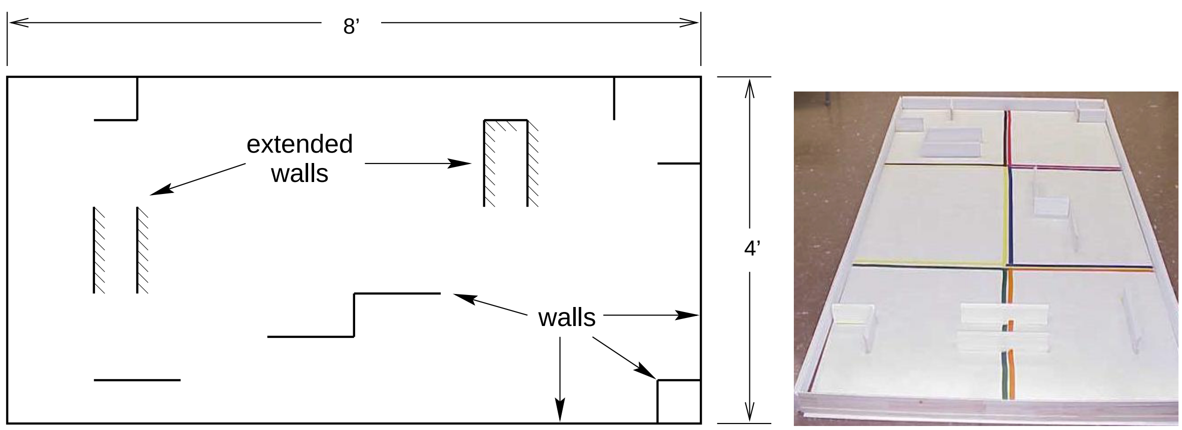
3.1 The predator/prey challenge

To encourage class discussions we wanted all of the students to be working on similar projects. However, we wanted them to have the freedom to be creative and explore areas that interested them the most. Therefore, we decided to pose a single "challenge" for the class. Each project must address the challenge, but students are given considerable freedom about what aspects of the challenge they work on and how they approach the problem.

We also liked the idea of focusing the project on a contest, such as MIT's Lego Design Contest [5], Trinity College's fire fighting contest [1] and AAAI's annual robot competitions [3], as a way to keep the project fun and motivate the students. As Pack, et al., observe, a competition provides a source of motivation for students to apply what they have learned and aim for high standards [7].

Therefore, we proposed the "Predator/Prey Challenge." The challenge is intended to model certain aspects of predators and prey in the wild. Two robots enter "the pit" at a time. One robot is designated the predator, the other the prey. Each robot has a light mounted on it to help the other robot identify its location. The predator's goal is to locate and run into the prey. The prey's goal is to avoid being hit. Each robot must be configured to run in either predator or prey mode.

The pit is a 4' by 8' area with 4' high walls added to provide obstacles and hiding places. For the base, we used tile-board to provide a smooth surface and to allow us to easily attach walls (made from floor paneling). Figure 1 shows the arrangement of walls that was used. The students were allowed to supply their robots with this map if they wished.



(a) design of the pit (b) actual pit

Figure 1: The pit for the predator/prey challenge.

At the request of the students, we extended some of the walls above 4' so that they would block the light mounted on the robots. This allows a robot to use the tall walls as a hiding place. As can be seen in the photograph in Figure 1 (b), we also added some colored tape to help robots perform rough localization.

This challenge provides many opportunities for interesting research projects. Some possibilities include:

- Develop a hybrid deliberative-reactive control system
- Learn a map of the world
- Adapt to your enemy's behavior
- Allow a trainer to teach the robot strategies

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3.2 The Mobile Robots

We considered a few different mobile robot alternatives. Our search for inexpensive mobile robots was narrowed down to a robot based on the Basic Stamp, the Lego MINDSTORMS system, and a robot based on the MIT Handy Board [6]. We looked into each of these and compared the amount of hardware-related work required, available programming environment, processor and memory capabilities, and price.

The robot based on the Basic Stamp had a nice platform and was inexpensive, but we felt the Stamp was limited in terms of programming capabilities. While the programming environment shipped with Lego MINDSTORMS is rather limited, there are several tools freely available on the Internet that provide better access to the processor's capabilities. However, the Lego approach tends to emphasize hardware design, e.g. trying to build a stable structure, and we wanted to focus on software. Therefore, we decided to go with a robot kit based on the MIT Handy Board. The Handy Board kit provided students with a three wheel base, using differential drive, on which students can add sensors and the Handy Board itself. This seemed to be the right combination of required hardware-intensive work and programming.

The contents of the robot kit we assembled are described in the Appendix. Figure 2 shows an example robot that one of the teams built. The robot is for the homework assignment in the class which requires students to build a light seeking robot.

3.3 Organization of the Project

The overall project was broken down over the semester into the following assignments:

Homework: The homework is intended to introduce students to the basics of using their robot. Students must assemble the robot, including selecting which sensors to use and where to position them, and program the robot to seek light. As part of the assignment, the students are asked to evaluate how well their robot is able to find light. They have to decide how to evaluate the robot including what to measure and what types of environmental conditions should be considered.

The deliverable for the assignment includes a presentation by the team describing their design and evaluation and a set of web pages documenting their robot.

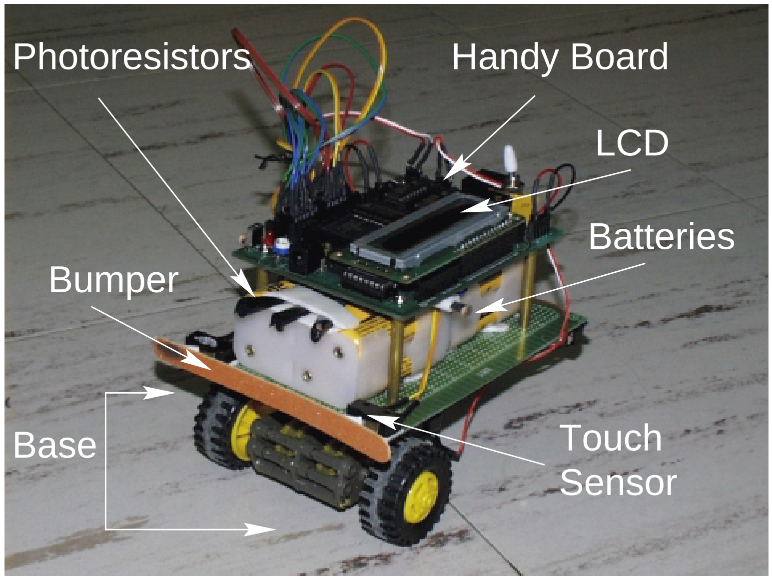


Figure 2: Example mobile robot.

Proposal: About half-way through the course, each team must submit a proposal describing the project they will perform with the robot. To facilitate class discussions, all teams are required to address some issue related to the predator/prey challenge, but are free to pick the specific topic and their approach to address the problem.

The deliverable for this assignment is a proposal outlining the objectives, proposed approach, evaluation plan and tentative schedule.

Presentation: At the end of the semester, students present their results to the class. In the presentation they describe their team's objectives, their approach and the results of their evaluations. The deliverable for this assignment is the presentation itself.

Report: Each team will also submit a report documenting their work and analyzing the results. The deliverable includes the report and an updated set of web pages.

4 Developing Research Skills

The main objectives of this course are to 1) introduce students to advanced topics in AI and 2) help students to develop quality AI research skills. Below we break down each of the basic skills we have tried to target and describe how the project touches on each of them.

Critical Analysis: Critical analysis is stressed in the readings, class discussion and throughout the project.

For each research paper reading, students write reaction papers in which they describe the things that they liked and disliked about the paper and discuss how they would extend the work.

To successfully complete a project, students must be able to identify the challenges in the problem they are working on, identify the approaches that are applicable, evaluate alternative approaches including pros and cons of different techniques and analyze the results of their work to explain what happened.

Creative Thinking: The course gives students a great deal of freedom. Students are responsible for choosing a problem to work on, selecting an approach to solve the problem, including the opportunity of coming up with a new approach of their own, designing the physical configuration of the robot and its software control system and designing a set of experiments to evaluate the project.

Evaluation: This skill was given perhaps the highest emphasis as it seems to be one of the less appreciated skills by students. Often students do not take responsibility for evaluating their own results, relying, instead, on their teachers to define the criteria for successful performance and assigning grades for their work.

The importance, and challenges, of a good evaluation is stressed throughout the course. During discussion of class readings, we talked about the ways in which the authors chose to evaluate their work. The first homework assignment required each team to evaluate how well their robot is at seeking light. The project itself requires students to come up with an evaluation plan during the proposal stage and follow through with evaluation and analysis for the presentation and report.

Effective Communication: Of course, a successful project is useful to others only if one can communicate the results. Thus, students are required to communicate what they have done in a variety of formats. They perform written communication in their reaction papers, proposals, reports and web pages and oral communication during class discussions and homework and final presentations.

5 Student Feedback

We felt that we designed a project to meet our course objectives, but we wanted to get feedback from the students to see how they perceived the course and the use of mobile robots in the project. We distributed a survey asking the students to think about what they learned in the course and the impact mobile robots had. Below we summarize our findings. 12 students participated in the study.

5.1 Question 1: What have you learned in this course?

In this question we wanted to find out what the students felt they got out of the course. Many of the students answered that they liked the coverage of material, mentioning concepts and particular systems that they felt were most important. This provides support that the course is meeting its objective to survey advanced AI concepts.

One student commented that the application-oriented curriculum helped them get a better understanding of the concepts:

> I now have a better understanding of the practical applications of all the AI theory that I've studied in the past. Most AI courses I had so far stressed the algorithms so much that you kind of lost track of what they were good for.

In terms of the course objective to teach basic research skills, one student remarked that the course taught them how to read and critique research papers and another commented that the course gave them the feeling of performing an actual AI project. We were also happy to see that a student indicated that they had learned the importance of evaluations and how to make evaluations more meaningful.

5.2 Question 2: Importance of Course Activities

The classwork consisted of four main activities:

- class discussion
- homework assignment
- project
- reaction papers

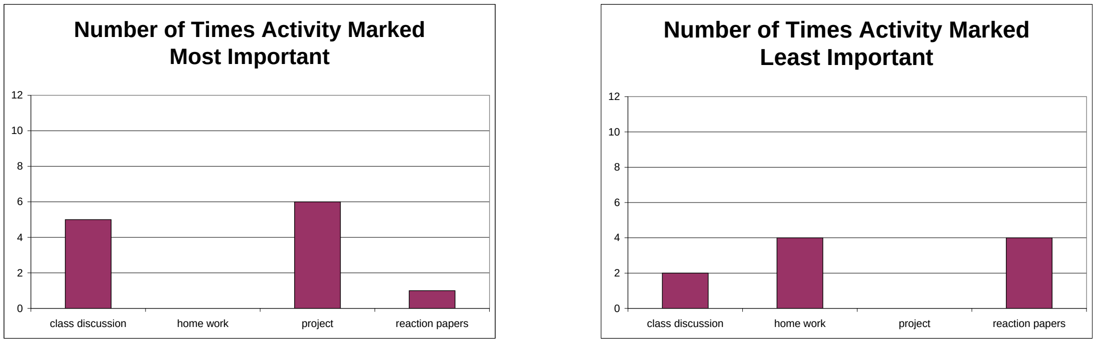
In this question, we wanted to find out which activities students found most effective. We asked them to rank-order the items in terms of the value they had for the course, using a 1 to indicate the most important and 4 to indicate the least important.

Figure 3 summarizes the results. Figure 3 (a) shows the number of times a student assigned a 1 to a particular activity, indicating that they felt it was the most important activity for the course. Figure 3 (b) shows the number of times a student assigned a 4 to a particular activity.

Half of the students felt that the project was the most important activity in the course, followed closely by class discussions. Homework and reaction papers were each picked by 25% of the class as the least important activity. It is interesting that no one picked the project as being the least important and no one picked the homework assignment as being most important.

We were pleased that so many students felt that the project and class discussions had value. It probably helped that the class discussions often made connections with the class project so students could discuss issues in class that they were struggling with in their project.

Although students did not tend to rank homework as highly as other activities, we believe that it is still a necessary component. It ensures that each team is able to get started with their mobile robot and get some experience working with the robots before writing the proposal. It may be worthwhile to change the objective of the assignment to make it more directly connected with a topic from the course. For example, rather than telling them to program the robot to find light, have them implement a technique that we have recently covered in class.



(a) selected most important

(b) selected least important

Figure 3: Results for Question 2.

5.3 Question 3: What did you think about the use of mobile robots in this course?

In this question, we wanted to find out what the students thought about the use of mobile robots in the class. The question consisted of two parts. First, we asked them to write down their thoughts on the subject. The next question asked them to look back at their responses and mark each responses with a '+', to indicate that they consider it a positive aspect of the class, a '-', to indicate that they consider it a a negative aspect of the class or a '0', to indicate items that are neither positive nor negative.

Several students mentioned that by working with actual robots they had a greater appreciation for the challenges that are involved in robotics. They also observed that mobile robots made it easier to observe the results of their work:

> [Mobile robots] provide immediate feedback. It is easy (fun!) to determine results.

Many students said that the robots made the course more fun and challenging.

One student commented on the challenges that the robots provided, indicating that he/she is neutral about whether these challenges are positive or negative:

> working with actual robots presents a lot of problems we wouldn't have if we just used simulation: noise, very poor sensors, non-homogeneous sensors, where the heck do I mount all these sensors?

About half the students provided negative comments. All of the negative comments related to limitations of the hardware. Some example responses were:

> Simple hardware prevents from utilizing advanced robot control systems.
>
> I only wish that we have more powerful sensors to make the project more challenging.
>
> I think we probably spent too much effort worrying about problems that were not really AI related.
>
> The sensors of mobile robot are not very robust.
>
> Also, the calculation ability of mobile robots is not very good.

These responses indicate that many students were experiencing frustration with the capabilities of the hardware. These concerns were also brought up during class discussions so we were not surprised to see them here.

To some extent, these problems are the result of trying to reduce the cost per robot. There are more powerful sensors for obstacle detection and localization, however, these would significantly increase the cost of the lab. Fortunately, high quality sensors are becoming more affordable. For example, Sharp recently released a nice range-finding sensor that can usually be found for under $15. The students were very grateful when we added these sensors to their set.

Of course, some of these problems arise from the basic challenges inherent in being a creature situated in the real world. These issues, which are often left out of simulations, are what make mobile robots an important area for AI research.

Some students also complained that the controller we selected did not have enough inputs for all the sensors they wanted to use. We may consider adding the Expansion Board for the Handy Board. This would provide about 20 more inputs and makes it easier to use servos. Unfortunately, it does not increase the available memory.

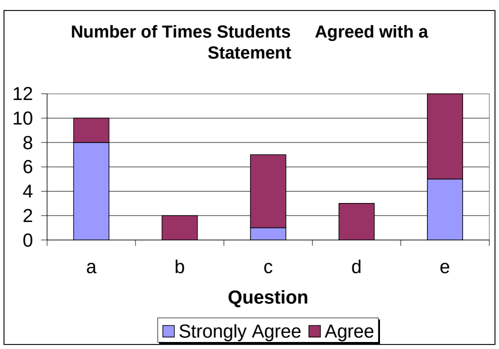
It is probably also worth considering modifying the challenge. With the limited sensors it is hard for a robot to detect another robot's presence until it is fairly close. It is also difficult to perform localization if the robot wants to use a map. Of course, localization is a challenging problem even with expensive sensors and it is good that the students have first hand experience with these issues.

5.4 Question 5: Specific Questions about Mobile Robots

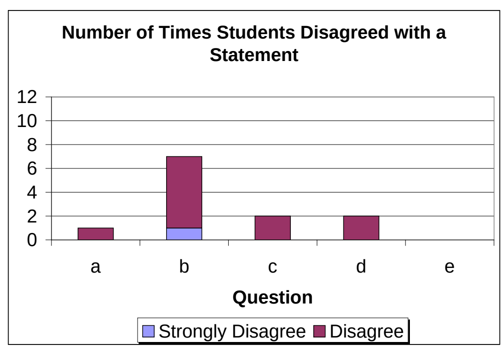
To get more specific feedback on the use of mobile robots, we asked students to respond to the following statements.

		Strongly Disagree	Disagree	No Opinion	Agree	Strongly Agree
a.	Mobile robots should continue to be used in future offerings of this course.	1	2	3	4	5
b.	Mobile robots should be used to a *lesser* extent in future offerings of this course.	1	2	3	4	5
c.	Mobile robots should be used to a *greater* extent in future offerings of this course.	1	2	3	4	5
d.	Mobile robots should be used in more courses in the Computer Science curriculum.	1	2	3	4	5
e.	I have learned things through working with mobile robots that I would not have learned otherwise.	1	2	3	4	5

Figures 4 (a) and (b) show the number of students who agreed and disagreed with each statement, respectively. In each graph, we have also indicated the number of students who indicated that they strongly agreed or disagreed with a statement.



(a) agreed with statement



(b) disagreed with statement

Figure 4: Results for Question 6.

Despite many of the negative responses about hardware limitations in the previous question, 83% of the students agreed that mobile robots should be used in future offerings of this course, with 66% strongly agreeing. One student disagreed with the statement.

Questions b and c indicate that more than half the students think the use of mobile robots should be increased in future offerings. There were mixed feelings about whether or not other computer science courses should use mobile robots. We do have a digital logic course in which the students build a line following robot. In fact, they have been using mobile robots for several years now. We are also discussing the possibility of using mobile robots in the introductory AI class.

The students were in unanimous agreement that they had learned things through the use of mobile robots that they would not have learned otherwise. 42% strongly agreed with this statement.

5.5 Question 6: Suggestions for Using Mobile Robots

The final question asked students if they had any suggestions for using mobile robots in this course.

Three students suggested changing the project so that it consisted of a series of smaller assignments or labs that reflected recent topics in the course. We agree this is a good idea, but it does detract from the objective of allowing the students to experience a research project. These individual assignments would be smaller in scope and have much more structure than a typical research project. It may be possible, however, to modify the homework portion of the project to address this issue. Perhaps having two warm-up assignments which focus on implementing current topics in the course before tackling the main project.

Some of the students wanted to use more complex robots for the project and one suggested that students have access to some of the more advanced robots in the research labs. These are good ideas, and we will look into this for future offerings. Of course, it will be challenging to coordinate class access with the research robots given the tight resource constraints.

6 Conclusion

In designing this course, we have attempted to meet two main objectives: 1) survey advanced topics in AI and 2) teach basic AI research skills. This semester, we have experimented with the use of a mobile robot project to meet these goals. From the student surveys and our own observations we feel that mobile robots provide the following advantages:

- they provide a concrete platform helping to make abstract concepts more tangible
- they provide a challenging environment in which to experiment with and evaluate AI techniques
- they are fun to work with

We also observed some drawbacks to using mobile robots, including:

- time and money required to start a new mobile robot lab

- limitations of inexpensive sensors and microcontroller can get in the way

Given the feedback from students and the results of the project, we feel that the course has been successful. The students have shown a sincere interest in the subject throughout the semester and have approached the project with enthusiasm. From the results we have observed, it does appear that the students are developing research skills. They are paying close attention to how they will evaluate their work and are communicating what they have done effectively in class presentations. While the primary focus of this work is on AI research, we believe the skills that our students learn from this project will serve them in many other disciplines.

A Part List for Robot Kit

- MIT Handy Board
- Mobile robot base with 2 DC motors/3 wheels (differential drive)
- Interactive C 3.2
- Soldering kit
- Sensors:
  - 4 Photocell sensors
  - 2 Infrared reflective optosensors
  - 6 Touch sensors
  - 2 Shaft encoders
  - 1 Heat sensor
  - 1 Sharp range finder sensor
- Miscellaneous:
  - Double stick mounting tape
  - Heat shrink wrap
  - Wire
  - Batteries
  - Battery holders
  - Handy Board DC Adapter
  - 0.1 inch male header connector
  - Resistors (22, 100, 300 ω)
  - Light bulb

Acknowledgments

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