PEER-TO-PEER LEARNING IN ROBOTICS EDUCATION: LESSONS FROM A CHALLENGE PROJECT CLASS

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Abstract

We report on our experiences with a project-based robotics class in which students designed a gardening multi-robot system, able to autonomously take care of tomato plants. We study the efficiency of different modes of interaction within the class and observe the emergence of peer-to-peer learning that has substantially contributed to the perceived learning experience. Results are based on an anonymous survey from a diverse student population with backgrounds from Computer Science, Electrical, Mechanical and Aerospace Engineering. We argue that project-based, collaborative learning is strongly beneficial to the students, and significantly extends learning that can be achieved during lectures and exercises alone, although requiring high effort and overcoming a steep learning curve.

Introduction

In this paper we describe our experiences with project-based, hands-on learning for robotics. Our approach to teaching gives students the opportunity to immediately put course materials into action. We have developed two undergraduate courses and one high-school robotics module that follow this philosophy. In each case, we organized the course project around a grand challenge that was inspiring and motivational to the students, yet solvable within the limits of the class. A project-based curriculum creates a need to know and apply new content and skills to the project, which is a broader challenge than applying lecture materials to a shorter scoped suite of homework exercises. Also, projects provide a tremendous opportunity for the students to learn from each other during the collaborative investigation of the problem. We developed the class "6.142: Building a Robot Garden" in Fall 2008 at MIT as a follow-up to "6.141: RSS: Robotics Science and Systems", an introductory class in robotics. Our goal was to expose students to the most important computational challenges faced by robots operating in a realistic physical environment—a garden. We developed a curriculum that exposed students to state-of-the-art advances in robotics, in the hope of actively preparing students for industry and research. Specifically, the students were given the challenge to design and implement a distributed robotic system that autonomously waters and harvests tomato plants in a green house we created for this purpose at the Computer Science and Artificial Intelligence Laboratory (Figure 1). We chose this task as it combines navigation, coordination, image recognition, manipulation and networking while imposing the real-world challenges of interaction with real plants (instead of simplified geometric objects). The plants were extended with computation and communication capabilities for interacting with robots. The students worked in teams to tackle different aspects of the system. At the end of the class the modules were integrated into a working autonomous green house. Significant data about the system performance was collected from experiments. The students' solution to the autonomous green house challenge had several innovative components, which were the subjects of a paper published by the entire class in the 2009 International Symposium on Intelligent Robot Systems [13]. At the end of this experience, we collected student feedback and evaluations using *surveymonkey.com* [1]. This survey enabled us to gather data about the individual learning experience and the efficiency of the different learning modules. These results suggest a strong beneficial effect of collaboration between the students for the perceived learning experience.

Figure 1: Tomato plants are arranged on a platform of 3x4 meters. Plants are illuminated by growing lights.

Related work

Project-based learning is being actively investigated in secondary education engineering curricula. Project-based learning is similar to problem-based learning, although requiring a larger time commitment and more self-directness by the students [2].

A survey summarizing the results from 28 independent case studies in project-based learning is provided in [3]. With each case study being a report compiled from teacher observations and student reports on specific classes taught, [3] extracts commonly encountered advantages and challenges of a project-based curriculum from mostly anecdotal descriptions. Particularly relevant observations for a robotics-based curriculum are the necessity of close observation of the students to detect problems early on [4], flexibility in lecture preparation to prepare students for the actual problems that appear during class in a "just-in-time" fashion [5], the need for mitigating the risk of cognitively overloading students with technology-rich projects that have a steep learning curve [6], the need for a "core of good and conscious students" for the overall success of the project [7], and the overall observation that project-based learning is not limited to teaching technical content but also social and presentation skills that are important for success in the engineering profession (see also [8]).

Robotics is generally perceived as a suitable substrate for project-based learning, in particular using the LEGO Mindstorm platform [9]. Also, there is a large body of work on developing platforms specific for robotic education (e.g. [10] and references therein) or on describing curriculum development for robotics classes (e.g. [11]).

Contribution of this paper

This paper provides a course description from a participatory, experiential and collaborative learning curriculum for robotics. The efficiency of the individual learning modules have been quantitatively assessed using a student survey and corroborate the effectiveness of a project-based learning approach and the beneficial interaction between students that we refer to as "peer-to-peer" learning. This paper also provides guidelines for the design of future project-based classes for robotics education.

Student Background

There were 13 students in the class (including the student with TA duties) of which 10 were male and 3 were female, 11 where in a BS program and 2 in a MS program at MIT. 8 of the students studied computer science, 2 were enrolled in both computer science and electrical engineering, 2 in Mechanical Engineering, and 1 student in Aero- and Astronautical Engineering programs. 9 out of 12 students stated that they planned on attending graduate school already before taking the class, one female student indicated that the course has motivated her to do so, two students did not change their plans to not attend graduate school after the class, and one student did not reply to the survey.

The class was advertised as a project-based class addressing a grand challenge in robotics with the potential for a common publication of the results.

Class Organization and Learning Goals

The class contained the following learning modules: ex-cathedra lectures to teach concepts and theory (1h a week), design reviews where the students presented and discussed their progress and next steps with teachers and peers (1h a week), as well as weekly meetings in the garden (1h a week) to teach individual concepts and address problems with hardware, software and algorithm design, and general work on the project.

After an introductory lecture and a brief poll questioning their individual preferences, the 12 students were divided into 6 groups addressing the following technical aspects of the problem:

- **System architecture**: how to connect individual software modules written in different languages? What code organization do we need?
- **Navigation**: how can the robot move from A to B on the garden platform hosting the tomato plants? How can we avoid collisions between robots?
- **Image recognition**: how can the robot recognize red and green tomatoes to inventory a plant and harvest tomatoes?
- **Visual servoing**: how do the joint positions of our four degree of freedom arm relate to the position of a tomato that we would like to grasp in an image captured from a camera on the arm?
- **Inverse kinematics**: how do we control the joint positions of our arm in order to reach arbitrary position in six degrees of freedom (x,y,z,pitch,yaw and roll)? Which positions can we not reach?
- **Networking**: how can we exchange information wirelessly between robots and embedded devices monitoring the humidity of each pot?

Two teachers, an ECE professor and a post-doctoral fellow, as well as a teaching assistant (TA) taught the class. Duties of the TA consisted of preparing and maintaining course materials, such as robots, software, the course wiki, and the source-code repository shared by the students as well as mentoring the students.

Each student team was provided with a mobile robot (Figure 2), a wireless router that can monitor plant humidity and a docking station (Figure 3). These components were developed by undergraduate students and the authors in the summer prior to the class.

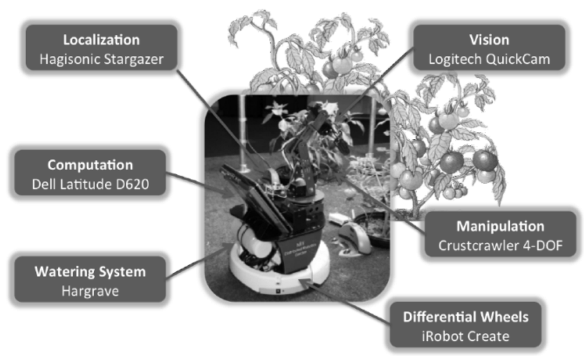

Figure 2: Robots are equipped with a 4-DOF end-effector, a monocular camera, an indoor, global localization system and watering device and are controlled by a notebook computer. Robots coordinate with each other and intelligent pots using wireless radio.

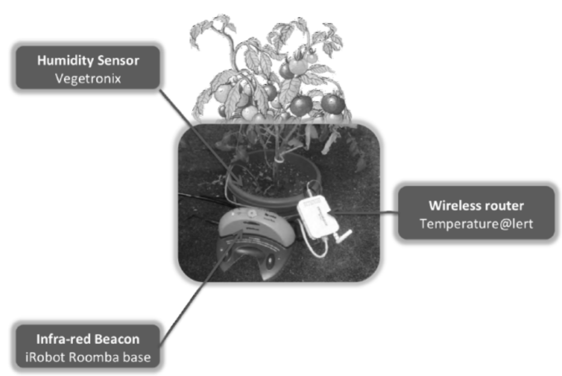

Figure 3: Plants are enhanced with a wireless embedded Linux device that can monitor its status using a humidity sensor and information collected by the robot as well as issue requests.

The first three weeks of the project were used to acquainting the students with this equipment by having them follow step-by-step assignments that lead to implementation of mini projects. Specifically, the students were required to implement a behavior that let the robot dock autonomously using on-board sensors, perform simple visual servoing (tracking a pink tennis-ball using the on-board camera), and communicating with the plant sensor via the wireless network. The students presented results of these assignments during the design review window.

Student assessment

Assessment of student performance is a challenge in project-based education [12]. As the different project components pose problems at different levels of difficulty, students cannot be graded based on the success of their contribution, but rather on the quality of their approach, which they demonstrate during the weekly design reviews, and in a final written report. We note that the class did not include a written exam. Thus, the success of individual learning modules is self-reported based on the perceived understanding of the topic in this paper.

Results

Technical results of this class are described in detail in [13]. Quantitative results in this paper on student learning are based on a survey conducted using an online tool "Surveymonkey.com" and include the 12 students and the teaching assistant (one of the MS students). The survey is available online [1]. The response rate was around 92% (12/13) after three solicitations.

Technical Content

We asked the students on which topic they have been working on, and how well they perceive their understanding of the other technical aspects of the project. Results are shown in Figure 4.

It turned out that almost all students perceived their involvement to go beyond their assigned task as they regularly answered "I was working

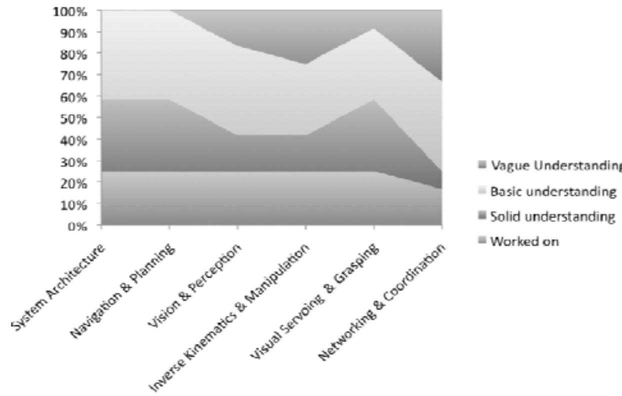

Figure 4: Level of understanding of technical modules vs. direct involvement in their implementation.

on component X myself" for more than one component. More than half of the class had asolid understanding of the overall system architecture (i.e. "I worked on this component myself" or "I have a solid understanding"), navigation and visual servoing, but only 20% of the students claimed this for networking. We believe the high confidence for some technical aspects to be due to the fact that students had significant previous experience with robotics, in particular in the course of the class "Robotics: Science and Systems" that covered system architecture, navigation and visual servoing, but focused on single robot systems. (4 students had both course work and practical experience, 4 students did only take courses, and 2 students had only practical experience due to competitions or internships. Only two students didn't have any previous experience with their project component.) 60% of the students claim to have had only a vague or basic understanding of inverse kinematics and manipulation. We believe this to be an artifact of the fact that one of the students implemented inverse kinematics using a robotics software suite that he had previous experience with, but which has not been introduced during the class. We observe the lowest perceived learning for networking and coordination (around 25% of the class indicate a "vague" understanding). Although networking and coordination were interacting with almost everybody else's modules, interaction between modules was abstracted by an inter-process communication framework and an understanding of the underlying aspects of ad-hoc networking were not necessary for most of the students in order to make progress on their tasks. Also, while some of the modules required strong mutual understanding of their inner workings, such as visual servoing and inverse kinematics, the actual coordination algorithms were of little importance for students implementing tasks involving only a single robot. Finally, as the students needed to overcome various challenges in navigation, perception and manipulation, actual coordination could only be implemented during the very last days of the class, limiting the exposure to this topic.

Efficiency of individual course modules

We also asked the students how much they learned during different modes of interaction within the class (lectures, design reviews, interaction with team partner, interaction with peers working on other aspects of the project, and independent work).

Learning from the team partner and peers working on other projects of the class, was valued high ("I learned a lot") by more than 50% of the students (Figure 2). Interestingly not only the effect of independent work was valued high by all students (all students either "learned a lot" or "learned something" from this activity), but also the interaction with their peers that worked on different aspects of the project.

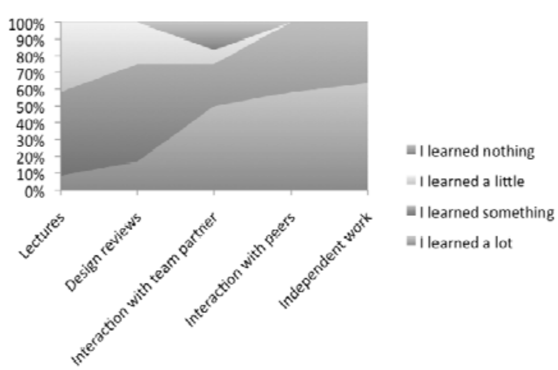

Figure 5: Perceived efficiency of different modes of interaction during class.

Due to the varying backgrounds of students, including some that could not pull their own weight in the team effort, interaction with the team partner has seen the highest variance in individual perception (from "I learned nothing" in 2 responses to "I learned a lot" in 6 responses). While all of the students agree that they learned a good deal ("learned something" and "learned a lot") from work on the project (including both independent work and peer interaction), only 60% of the students have this opinion on the lecture and 40% of the students reported that they learned "little" during this time, with only one student that "learned a lot". This is also the case for the design reviews - students presenting their progress and ideas in front of the class - received a "I learned a lot" from only two students.

We also asked students, whether they relied on literature not distributed during class in order to research their aspect of the course project, which 50% of the students did.

Summary and Discussion

We have used project-based learning as a capstone experience of a wider curriculum in artificial intelligence and robotics to promote the integration of subject material and providing a hands-on experience to the overall engineering process.

Despite the very specific tasks that student teams were working on, we have shown that project-based learning can indeed lead to the acquisition of a broad knowledge base. Indeed, 70% of the students assess themselves to have gained a "basic understanding" of the 6 technical components of the class, 80% of 4 technical components, and more than 90% that have a basic understanding of half of the topics taught.

It turns out that peer-to-pear learning, i.e. learning from other students that work on the same or related project, is perceived as providing a substantial learning experience, and the amount of knowledge acquired seems to be at the same level as that learned during individual study. From this perspective, project-based classes seem to be superior to classical models that rely exclusively on ex-cathedra lecturing and individual study. Designing a project-course that covers the same breadth as a lecture-based course is difficult, however, and an implementation challenging and time intensive for the students. Although lectures and design reviews were not perceived as the most efficient learning vehicles by the students, we believe both of these offers were necessary for the success of the project. The lecture provides the theoretical basis for the students' own exploration and provides a common ground by defining the scope of the project. Also, the fact that the design reviews require deliverables on a weekly basis keeps the progress of individual teams within sync, and it is unclear whether - particularly bigger classes - could efficiently self-motivate themselves. One way to increase the value of the lecture could be to design the lecture in response to problems encountered during the project, in order to maximize the opportunity for the students to put theory into practice.

Although the perceived learning experience is good and extends that of a "talk and chalk" based lecture by additional modes of interaction, we note that the class required considerable effort not only from the students, but also from the teaching personnel for preparing lecture materials. It turns out that open-ended projects bear a high-risk of failure if the students are unable to overcome the steep learning curve that is required to commission and operate the hardware and software tools, which essentially requires a core of exceptional students [6,7], which are not always available. Also, students need to be continuously monitored in order to anticipate dead-locks of the project that can only be overcome by technical support from the teacher [4] or even acquisition of additional hardware. We therefore feel that project-based learning is most successful if the students can work with reliable components and the teaching staff has a very clear idea for a possible solution to the posed problem that can serve as a blueprint.

Finally, we observe that the definition of "learning" in the survey has been left open and we assume students comments can be understand with respect to their learning experience of technical content, but not reflecting their inter-personal and presentation skills. As we believe project-based learning to be highly beneficial for the development of these skills – be it by having to deal with weak students in the team or by presenting design reviews – we will try to quantify these observations in the future.

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