TEAMWORK AND ROBOTICS – A LEADERSHIP EXPERIENCE FOR UNDERGRADUATE ENGINEERING STUDENTS

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1. INTRODUCTION

A multidisciplinary Teamwork and Robotics course was taught at Rose-Hulman for the first time in spring term, 2004-5 and will be repeated for spring, 2005-6. We report on the goals and progress of this course development, including changes planned for its second offering. This is a unique, experiential, laboratory course combining the topics of service learning, robotics, and advanced teamwork skills.

The course is needed partly to supplement Rose-Hulman's support of Botball programs in middle schools and high schools. This program is described in Botball (2006). The course thus gives engineering students a team leadership experience, working with younger students primarily via distance learning channels. It also gives them a challenge in collaborative learning, since both their team and the younger team they are helping are newly formed, with short-term goals.

In a second part of the course, the college teams work on their own, more complex robotics projects, a part of the national "Beyond Botball" competition. The formulation of the problem and its solution are both up to each team, thus testing their creativity and ability to self-organize, on top of their learning and application of related technical skills. An additional research paper project was included at the end of the course as an extension of these two main parts.

The primary goal of the course is to teach teamwork in a very diverse student environment. The vehicle for this social learning is the simultaneous acquisition and sharing of engineering skills, in this case directed toward students' interest in robotics. The program differs from capstone courses in being focused on a strong common interest in a specific topic – robotics. It includes a chance to mentor a team of junior developers (the younger students). And in its second part it requires teams to act as their own client in goal-setting.

Rose-Hulman's students typically go on to assume leadership positions in engineering groups and their businesses; teaching leadership skills even at the undergraduate level is therefore a priority, as noted by Chenoweth (2005). This course is a part of that overall focus.

2. INITIAL COURSE TRIAL, 2004-5

In computer engineering it is common to use robotics as a vehicle for teaching teamwork. At Rose-Hulman, this is part of a two-course junior year preparation for capstone projects. While teamwork is one goal of such courses, it is mixed with the learning of engineering processes for one particular discipline. Many of these other skills may be unique to a particular discipline. Reference, for example, Chenoweth and Yoder (2004) for a comparison of processes used in computer engineering versus software engineering. The students in such courses, understandably, also represent a single discipline.

At the same time, teamwork is a skill perceived as being of growing importance to engineers. Because of the skill's value to employers, teamwork is now seen as one to be taught to undergraduates, not left for after graduation. Thus, for example, almost every course taught in the Computer Science and Software Engineering department at Rose-Hulman includes a teamwork component.

It is not clear, however, that these curricula provide an opportunity for students to learn more advanced teamwork skills. We therefore invented a course, the subject of this paper, whose primary emphasis was teamwork, called Teamwork and Robotics. The course was first offered in the spring term, 2004-5. Its more advanced teamwork goals included the following:

(1) Having much more diverse teams involved in engineering, including people outside the institute;

(2) Having a variety of extensive team leadership challenges included, particularly, the mentoring of younger students;

(3) Working daily with people representing a wide range of technical expertise; and

(4) Students' setting their own agendas in a non-pedagogical environment.

2.1 Course planning

Because Rose-Hulman is an engineering school, we picked a specific engineering topic with wide appeal as the vehicle for developing these teamwork skills – namely robotics. The new course also filled a gap, a way to augment Rose-Hulman's program supporting Botball programs in ten to twenty regional middle schools and high schools. Botball is a national robotics competition beginning in March and going through May. That timeframe coincides with the institute's spring term schedule. The course therefore could be associated with a seminar for training Botball sponsors and teachers in these schools, and then go on to supply Rose-Hulman students as teams of mentors. Botball is described as a "hands-on learning experience in robotics designed to engage students in learning the practical applications of science, technology, engineering and math." The program is detailed in Botball (2006). It is sponsored by the Kiss Institute for

Practical Robotics, a "private non-profit community-based organization that works with all ages to provide improved learning and skills development through the application of technology, particularly robotics." See Kiss Institute (2006). Each Botball group typically develops into a high-performance team in creating a successful robot for the annual competition. Supporting the development of these teams was a natural target to help meet the above four goals of the Teamwork and Robotics class.

Based on these goals and ideas, detailed course objectives were set as follows:

1. An understanding of how to work effectively in teams, including (but not limited to):
    a. The importance of creativity and how to combat blocks to creativity.
    b. The importance of specifications and how to express them.
    c. The roles of team members and how to conduct effective team meetings using those roles.
    d. How to reach consensus and how to handle conflicts.
    e. How to manage the progress of the team using task lists and other techniques.
    f. How to develop alternative designs and choose among them.
2. The goals of written, oral and interactive communication and how to effectively implement them.
3. An awareness of how professionalism impacts one's career and how to maintain professional standards in one's work.
4. An increased understanding of technical subareas of robotics, e.g. the design and use of sensors, software development of concurrent code, path planning, vision, or programming language design.
5. An ability to help others understand what engineering is and why it is fun.
6. The ability to integrate the above mentioned course goals in the successful completion of course projects.

Aside from general course division into the two team-activity parts, the daily agenda for the course was left open, in concert with the non-pedagogical objective of developing team leadership. The research paper activity was added, in order to challenge experienced students and also provide a written outcome: "Investigate a technical area of robotics and write a report explaining what technical ideas the student learned from the investigation."

In a promotional message sent to all Rose-Hulman students at spring registration time, the course was described as service learning, with the opportunity to work in teams to design and build a robot, and to mentor the middle school and high school students in the Botball competition. The robots designed for the class could further compete in the annual Beyond Botball competition, which was a draw for some students. As explained at Beyond Botball (2006), this competition is as follows: "The game is played on a 4' x 8' board. Your robot competes by using robot design and strategy to move objects into scoring position in a challenging robot face-off. Following robot guidelines, Beyond Botball participants build robots using any building materials, processors, and sensors they feel serve the objective of the game." The competition is open to anyone beyond high school age, but most entries are from college teams.

2.2 Course delivery and outcomes

Twenty-three students completed the initial course offering, with demographics as shown in Table 1:

Table 1: Demographics of the Spring, 2004-5 Class

Category	**Analysis**
Year in school	Freshman – 4 Sophomore – 5 Junior – 3 Senior – 11
Major	Computer Engineering – 8 Computer Science – 5 Electrical Engineering – 4 Mechanical Engineering – 5 Physics – 1
Sex	Men – 19 Women – 4

The students had a time for organizing and building teamwork skills prior to engaging actively with the high school and middle school teams. No textbook was used; but techniques were pulled from a variety of sources, including the instructor's own extensive experience in working with teams of younger children building robots.

In regard to the developing of advanced teamwork, the non-pedagogical course delivery method was used intentionally to test student leadership. Aside from initial guidance on teamwork, the work was entirely self-directed. In the first class, for example, some pointers and tools were given for distance learning with the teams of younger students, but choices and trials of these ideas were left up to the teams. Technical skills would come from the students' prior knowledge and from their independent study. The goal was to increase students' ability to learn new material in a self-directed team environment. As Table 1 shows, the students came from varying backgrounds; they largely had not worked together before.

Rose-Hulman teams from this class became associated with their external teams beginning at the March Educators' Workshop for area middle school and high school Botball leaders. These leaders were a mix of teachers and parents who had an interest in the Botball program. Some had experience from past years, and some were new. The main emphasis of this two-day seminar is to distribute

Botball kits (of Legos and associated parts), describe that year's contest, and discuss fundamentals for the benefit of beginning leaders. The Rose-Hulman teams met and worked with their associated teams at this two-day conference.

Following the seminar, Rose-Hulman teams were charged with developing a successful relationship with their high school or middle school team. Building this relationship posed unique obstacles, because of the different levels of experience of the latter teams, and also because of the proximity or remoteness of those teams. Some, for example, were in different states and remote communication with them would be the rule. A typical conversation might include explaining to a student or to a Botball leader how to mount a servo onto the robot, with the Rose-Hulman student being an expert at this but not being able to see the actual robot they were helping with. Thus, they might need to refer to shared documentation about gears and frames, and use that documentation to lead the remote, inexperienced person through a model of the assembly task as a basis for helping with the real task. One Rose-Hulman student summarized, "Distance teams tend to only ask for your help when they are in trouble, and not when they have something good to say. It's also hard to read emotion and other feelings when you're communicating over emails, IM, or phone."

Regardless of the distance involved, the Rose-Hulman teams had to deal with the issue that various skills were called upon at different times to help their associated teams. Different people from the class's team would be involved; yet they needed to provide a consistent interface with the other team. This challenged their leadership abilities and ingenuity. They also had to face issues caused by the cultural differences between college and the environment of those they were helping. As one student put it on the post-course survey, "Kids don't seem to expect, or want, a whole lot of help." Put another way, interesting them in the help available from the college team was a challenge in itself.

One Rose-Hulman student summarized the challenge of working with younger students as, "I learned a lot about how to relate suggestions and proposition[s] to another group of people in a way that gets the point across, but allows the group to think on there own." Another said, "I learned a lot about relating advanced topics to a younger generation in a way that was helpful, but not too oppressive. I also got a taste of what a consulting position might be like, as my group asked many many questions. Finally, I learned that … many students are quite capable of making great robots. They just need the confidence to do so." Even when the teams they were supporting were not successful, the college students learned teamwork lessons. One said, "I learned that organization is key when making a team effort. My partner and I had some trouble in the beginning with relating to our Botball contact. And when we eventually did communicate with the team, we had trouble finding a time to meet. Though everyone put in a good effort, things were just not worked out in time."

High school students who had received help from the Rose-Hulman students reported that the latter were very technically competent, life savers when needed, but they also stood back and let the high school students try things on their own.

Underclassmen wished they could have a similar experience working together the next year.

Additional feedback was heard that the presence of the college students while the Botball teams were working tended to stop arguments among the high school students. That is, when different views couldn't be reconciled on their team, they would appeal to a college student for advice. Often, this was more than the college student's just saying who was right. Instead, the college students were able to bring out additional thinking on the team they were helping, to lead them to their own conclusions.

The high school students reported one systematic problem: At the beginning, when they needed a lot of help learning about programming and about robot assembly, there were not enough Rose-Hulman students to go around.

The opening, service learning aspect of the course was deemed to be successful. Here again, student comments showed individual lessons contributing to that overall conclusion. One said, "After I switched Botball teams to help a school more in need than the one I had been working with, I found that people are more willing to listen to criticism and suggestions than I had originally thought. From the beginning I doubted how much we could help these young teams, but I found that we really did make a difference." Another typical comment was, "I learned more about how high school kids think and helping them with coding was a great joy. They did not usually understand what was going on with the computer code so they needed lots of help there."

In the second, internal project part of the course, students built their own Beyond Botball robots using Legos, HandyBoard and Mindstorms controllers, and many types of motors and sensors. Some teams used other, even more sophisticated, robotics parts. In this project they became more focused on the technical aspects of the work. However, teamwork skills still played a clear role. One student said, "We learned to think together as a team, and to resolve any possible conflicts through further brainstorming." Another elaborated on the difficulties of being a part of a team that is larger-than usual for college projects: "I learned that it is really hard to stay focused and on task in a large group. ... Our [Beyond] Botball group had 10 or 12 people in it (there are so many I can't remember!), and we had to keep splitting up the team into subgroups to make sure we all had tasks. At the end, it was even harder to put all of our pieces together. It sure was a learning experience."

The third, writing assignment part of the course was an individual one, though it did build on top of the main, collaborative projects each student had engaged in. Themes of social responsibility were discussed in some of the papers. One student commented, "I found out that the latest technologies are heavily dependent on robotics and robot technologies. It is crazy how the Jetson's television show isn't that far off from reality. It is also sad how robots are starting to take away regular everyday human jobs, and that soon, robots will probably be taking over the world once they develop their own sense of intelligence."

All the students were successful in completing this course, with grading based on a combination of documented observation, peer grading by the teams, and evaluation of the written research paper.

3. PLANNED SECOND OFFERING, 2005-6

A goal of this paper is to get collegial feedback on the direction of this program, which clearly is work-in-progress. The plans for a second offering are underway; they include both improving on the experience seen in the first class and also adding more structured team-building content.

Thirty-three students are enrolled for this class. Two instructors rather than one will be in the room, with the second being especially experienced at team-building activities. The new team-building goals are described in Section 3.1, below. The engineering goals of the course will remain the same as last year. However, we would like to have some interactions such as peer review and team interactions also included into the research paper writing.

3.1 Team-building goals

For students in the class, a part of the challenge – what is advanced about the class – is the variety of situations in which they must lead or be a part of a team. These situations very much stretch what they already have been exposed to in their college experience.

The learning of teamwork in this class has four major interactions as shown by the arrows in Figure 1, *below*, and these have different facets suggested by the numbering of the arrows. Facets 1, 2, and 3 are the teaching of teamwork directly to a team, in a chain starting with the college instructor teaching this to the teams of college students in their Teamwork and Robotics class. This then continues with both the latter and the middle / high school teacher teaching teamwork to the middle / high school teams. The related but additional facet is that the college instructor must also teach the college students how to teach these skills, and they must teach the middle / high school teacher this same set of skills. The end result is that the college students learn both facets of teamwork – how to use it on a team and how to teach it. The middle / high school teacher knows how to teach it. And the middle and high school students learn teamwork as a part of creating a Botball robot contestant.

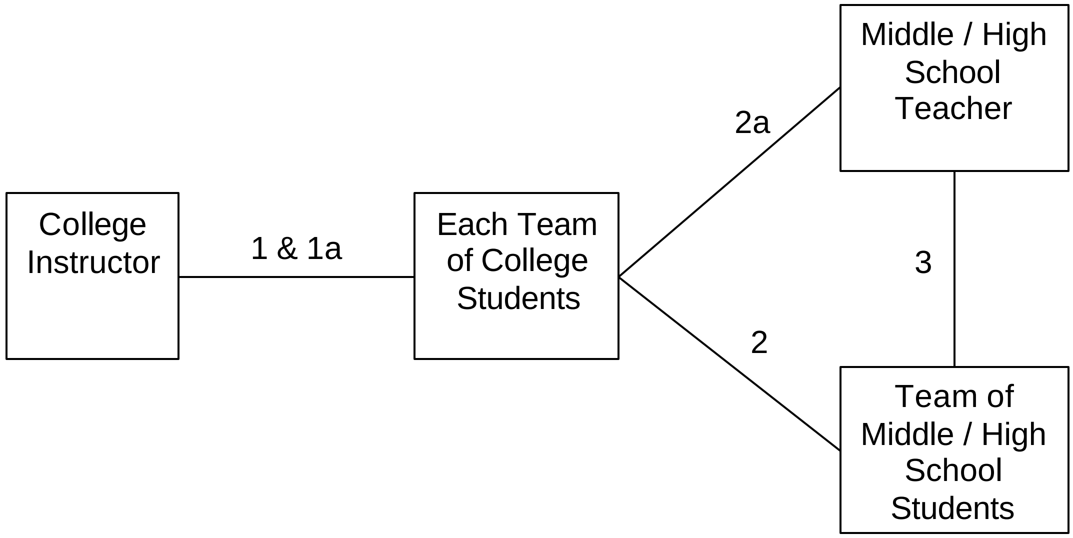

Figure 1: Chain of teamwork learning from the course.
Legend: 1, 2 & 3 – teaching teamwork to teams;
1a & 2a – teaching how to teach teamwork.

How does the college instructor learn the teaching of these skills? It is essential that they have had high quality team experiences themselves, and that they also have had training specifically on how to teach teamwork. Effective training in this subject is not just live, but also experiential. The ability to make any of the interactions shown actually work depends in part on the culture of the schools involved. At Rose-Hulman, teamwork is an intrinsic and valued part of student culture, with many faculty members experienced at teaching the underlying skills. This surely makes it easier for the chain reaction shown as the work of this class to be successful.

There also are many resources available for ideas on specific aspects of teaching teamwork. For example, we have found team forming activities which can be used in Federico and Beaty (2003), Leigh and Maynard (2002), Thiagarajan and Parker (1999); Maxwell (2001); and Larson and LaFasto (1989). A large number of resources also exist for session openings, brainstorming and creativity with groups. We are using Epstein (1996), Newstrom and Scannell (1980), Caroselli (1998), and Collier (1994).

Some lessons of team-building are particularly applicable to an activity such as constructing a robot together. The following expected learnings will receive increased emphasis in the course this spring:

1. The robot is a system, and so all the parts must work together. This suggests a collaborative climate, one which emphasizes teamwork. Everyone adds value. There is a need for other people to achieve the goal. Other people bring in ideas the individual has not had, ideas which help. To any one individual, the task seems possibly overwhelming. It is not easy for one person to imagine

exactly how to solve it. The courage of the group working together overcomes these doubts.

2. The goal of the construction activity is clear, and worth teaming and sacrificing for. The team can gain a tangible success from this joint venture. This makes it feel worthwhile, and drives the teamwork. Use of corroborating sources that confirm support for this goal also help – the fact there is external funding, external interest, student interest in related subjects, recognition and tangible rewards. The teamwork has a results-driven structure – one that can be tested by the outcome of the task.
3. There is a need for strong, principled leadership to maintain the organization and progress of the activity. This does not mean a particular style of leadership must be followed; it does perhaps suggest that the style must be something understandable to those participating. Anomie is sure to fail. The teaching of teamwork can very much include setting a leadership example with opportunities for students to model that on their team.
4. The value of effective communication is self-evident in this environment. Conveying incorrect instructions to another team member results in immediate problems. High school and middle school students need particularly clear and specific instruction, in comparison to college students.
5. There is a need for people playing different roles on the team, as exemplified by the different aspects of robot construction team members engage in. For example, the need for catalysts on the team can be seen, such as people who notice mistakes or ways to improve the way others are doing things.
6. Everyone needs to be engaged for success. Team members need to learn how to motivate one another, and leadership is as much inspirational as technical.

We would like our class to understand how team projects can be seen as an adaptation, as the team members learn about the task and the available tools and parts for building their robot, and learn about one another. They also can see specific outcomes of the phases the team passes through as they work together – forming, storming, norming, and performing, as Tuckman (1965) described.

One example of a more structured team building activity for this environment would be delivery of the class teams to another of communications intended for the high school and middle school teams, so that the class teams can critique each other. Another example would be a guided retrospective activity, which can yield perspective on the teamwork process each team has just been through. We intend to teach related techniques and frameworks for thinking about teams, in the new course offering.

We believe that in the second trial of this course, some of these core areas of need for teamwork and their related skills will become more formalized or conceptualized as a part of the learning.

4. CONCLUSIONS

We would speculate that as teamwork continues to grow in value, as a goal of undergraduate engineering education, we will see the need for more courses whose main emphasis, rather than ancillary emphasis, is on the learning of teamwork. Teamwork and Robotics could be a prototype for such a course.

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