Management of a Large Team-Design and Robotics-Oriented Sophomore Design Class

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Abstract - Development and implementation of innovative, team-oriented, undergraduate design experiences can stimulate innovation in the engineering curriculum. However, combining team design with a hands-on technical realization experience can become unwieldy for an engineering program, due to the management of materials, students and instructors. Northern Arizona University has developed a management scheme for one of their large team design classes which allows for a controlled environment in which the class can be presented, yet flexible enough to incorporate ongoing changes each semester. The interdisciplinary sophomore design course – EGR 286 – is a relatively large class size for a single session, enrolling up to seventy students. It requires the coordination of over twenty student teams, each using separately assigned, university-owned, Lego® Mindstorm kits and accessories. The teams are eventually merged into a smaller number of larger teams by mid-semester. The assignments and anonymous student peer evaluations are managed through the adaptation of a distance-learning web-based system. The logistics of the team assignments, kit issue, student teaching assistants and computing/laptop management are addressed. The management scheme has resulted in an ability to allow several different instructors to teach the class with less difficulty. Another result is that the management structure allows for new projects and even new equipment to be implemented without changing the underlying teaching objectives.

Index Terms – Engineering education, Class management, Robotics Education, Mindstorm, Legos.

INTRODUCTION

The College of Engineering and Natural Sciences (CENS) at Northern Arizona University (NAU) offers a unique approach to “engineering design” education. In its “Design4Practice,” or “D4P,” curriculum, a series of team-oriented, project-based classes are offered to the students in each of their freshman, sophomore, junior and senior years. The program objectives were developed in response to a call by industry supporters for baccalaureate engineers to possess a broader set of skills beyond their analytical and computer skills. This call was strengthened by the Engineering faculty’s observation of the students’ experiences in senior capstone design during the late 1980’s and 1990’s. These students, who had had no prior experience with a design process, struggled with the issues of realizing a design, problem solving, project management, and teaming issues. Their successes were limited, hampered not by a lack of technical knowledge, but because they lacked skills and experience in working with others towards a common project resolution.

The sophomore design course, EGR 286, is the earliest D4P course where students fully integrate their current level of engineering education with a weeks-long, team-based design activity. The design teams are each comprised of Electrical, Mechanical, Civil, and Environmental students. EGR 286 was and is currently the showcase course of the Engineering D4P curriculum.

In the process of developing this course over the years, the author noted that very little detailed information in the literature is available on how active-learning oriented classes are actually managed logistically in the classroom. The author hopes that the information put forth in this paper can serve as a guide for other engineering educators who intend to offer active-learning classes with technical media.

I. Legos Mindstorms®

Lego Mindstorms kits are used in the course format for creating the robots. Legos are used for a very simple reason: These literal building blocks allow for physical prototyping without the student needing to have great mechanical skills. Moderately complex systems can be designed and built quickly; such an example is illustrated in Figure 1. Another equally important reason for using Legos Mindstorms®: The educational institution does not require extensive manufacturing facilities, tools, and space for constructing prototypes if Legos are the primary mechanical prototyping media.

Using Legos for physical prototyping is very prominent in undergraduate engineering education. [1,2,3,4,5] The use of Legos to allow a design process to culminate in a physical product for even the earliest of undergraduate classes. Many freshman engineering courses use Legos in this manner. [6,7] Yet, Legos are not considered by many to be simply “toys.” They can be used at higher levels with the use of the robotic controller, Mindstorms® RCX. [8,9] The EGR 286 course
incorporates the RCX as a robot controller. The students are instructed in both autonomous and semi-autonomous concepts of robotic control with these controllers.

![Image](image_url)

**FIGURE 1. A LINE-FOLLOWING, LINE MEASURING ROBOT. A UNIQUE FEATURE FOR THIS TEAM'S DESIGN ENABLES THE ROBOT TO MAKE TIGHT TURNS WITH THE TRAILING MEASURING DEVICE.**

EGR 286 is primarily a project management and team-oriented design course, even though an outsider could initially interpret it as simply a robotic design class on its surface. Characteristics of the course construction include:

1. The first eight to nine weeks of the semester would involve teams of three to four students each.
2. The small teams would work on weekly “short projects” which address specific technical issues of the larger project to come.
   a. One or two of the last short projects could involve two teams, working together, creating essentially a six-person team. These more elaborate projects would be conducted over two weeks, but are still considered a “short project.”
3. The course would culminate in a complex robotic project, requiring the efforts of roughly 10 to 12 students in a single “megateam.”
4. This “large project” (also known as the “final design project”) would be conducted over the last six to seven weeks of the semester.

Each semester can see variations in the format—for example, a team of instructors may wish to have a more complex final design project, and thus eliminate one of the smaller projects to enable them to add weeks to that last project timeline.

**II. Small Team Format**

By working in smaller teams at the start of the semester, individuals gain immediate ownership of the technical knowledge required to tackle the larger, complex final project. The smaller teams also begin to work in larger groups by being paired with other teams for the last one or two short projects. This procedure allows for a ‘growing’ of teamwork and planning in intermediate-sized groups, before being finally organized into a single, large megateam for the final project. This schematic is illustrated in Figure 2.

![Diagram](image_url)

**FIGURE 2. COURSE PROGRESSION. NOTE: 15 OR MORE SMALL TEAMS PER CLASS START THE SEMESTER.**

All students are required to learn NQC (“Not Quite C”) in the short projects as well as in the final project. NQC is a programming language developed as freeware, specifically for controlling the RCX controllers with a C-like command language. It has several advantages and disadvantages, but is chosen for this class because of its similarity to the C programming language. [10] This similarity with C exposes the students to programming with physical-world outcomes. Each small team would have an RCX as the core controller for their project, and the final design project would incorporate at least one (typically, four or more) RCX in the controlling system(s).

There are multiple, three-person teams created; these teams may be considered “agile teams,” as they are small enough to rapidly address a design project, create the design, and test it, all within a week. Due to administrative issues (late class enrollments, initial limits on equipment resources), several four-person teams are also allowed. The team’s grade for a weekly project is a combination of three graded products as listed below.

- The software grade (20%)—the controller program for the project is turned in for review by the instructors. Graded components include the correctly formatted filename, a commented header, commenting throughout the listing, and correct formatting for readability.
- The project demonstration grade (40%)—the robot is physically demonstrated on “demo day” for that week. The students are assessed the success of their project by their level of meeting/exceeding requirements set forth for the robot in the project requirements document.
- The written project report (40%)—the team must write a report which details their creative process, construction, programming, and testing processes for that week’s project. A primary concern is effective, grammatically correct writing. Increasingly correct flowcharting for the robot’s ‘behaviors’ are also required, as a method of documenting the intended function of the robot.
With three students or more in a team, an anonymous self-evaluation “peer review” process is possible for both the small projects and the final project.[9] This procedure is typical for many published peer evaluation procedures.[11,12] An electronic survey is opened at the end of each project, allowing the students to evaluate their teammate’s contributions to the overall team project. The course instructors take these evaluations along with their own observations. The individual peer evaluations are averaged and used as a scaling (or multiplying) factor against a particular team project grade. Typically, a student’s average peer evaluation ranges from 0.70 to 1.10. In addition, the instructors carefully consider whether or not to adjust the scaling factor higher or lower for any given project. Such considerations may include: A team could have done poorly due to one member not participating properly. Thus, the other members should have their raw score improved slightly. Conversely, a non-performer in a team might be rewarded from excellent efforts of the other performers on the team. Thus, that non-performer’s team score should be penalized. Either situation is documented carefully by a combination of the peer evaluations, attendance sheet records, and/or written observations from the instructors. The students’ peer evaluation input has become somewhat automated. This automation process in the context of web-based tools is addressed specifically at a later point in this paper.[13]

The weekly class format is structured such that there are three lecture hours and two “recitation” hours, illustrated schematically in Figure 3. A short project is introduced on a Wednesday and demonstrated on the following Wednesday. Fridays usually contain technical presentations for the students, relative to the upcoming project demo. Monday can follow with more technical information, but typically, the entire two-hour session on Monday is dedicated to team design and construction activities. In general, the two “recitation sessions” are actually devoted to the team activities, where the students discuss their upcoming designs, implement their design ideas, and test their designs. Instructors and student teaching assistants (TAs) are available to assist the students with problems they may have during these active sessions. Most of the problems arising are associated with programming issues, as many of these students are introduced to programming for the first time in this course.

III. Technical Knowledge Supports the Large Project

The large project is an automated system (i.e., a robotic system). As such, it will require sensors (light, infrared, contact switches, rotational, thermal, etc.) and outputs (motor or light). Each sensor and output topic is individually targeted, such that they can be individually addressed in a small, week-long project. For example, if the final project requires a line-following robot which has a container that will dump materials at the end of the path, then there may be three short projects created to support it:
1. a line following project,
2. a mechanical design project (for the dumping mechanism), and
3. a contact-switch project (for the dumping mechanism at its limit).

![Figure 3. WEEKLY ORGANIZATION FOR "SHORT PROJECTS."](image)

COURSE MANAGEMENT ISSUES

An objective of the course revisions in 2004 was to allow for the dedication of only one faculty assigned to the class; currently, two to three faculty are assigned. However, this single-instructor concept was never implemented. First, the class continues to be fairly complex in implementation—with large sections of 40 students or more, multiple faculty are necessary to run the very active-learning environment. Secondly, a training process is needed to get faculty to understand the course pedagogy. Training funds for a summer orientation never materialized. As a result, faculty are instead trained by being assigned as part of the two-to-three instructor assignment per section, where there is at least one experience faculty member, shepherding the rest.

The short and final projects are documented in a network-located, faculty-restricted-access set of files. An instructor can select a final project from the database, then choose five to seven short projects which will support that final project. Alternatively, the instructors can choose to implement any number of new short projects, or even a new final project. Once implemented, the new creations go into the database.

Team organization and management is a major undertaking at the start of the semester. The goal is to have three-person teams organized by the second day of class. However, for practical considerations, the instructors are required to accept late-registering students by as late as the third or fourth class session. This problem results in the first short project being, in reality, two weeks in length, as the late enrollees are incorporated into several new teams. This “long short-project” has other advantages as well—it allows for logistical time to enable the issue of course materials, i.e., issue of the Lego Mindstorms® kits to the teams.
After the second short project, the teams are reorganized again into three-person teams. This approach is accomplished so that the students have another teammate for the remaining projects. The procedure also enables the instructors (if so motivated) to place observed underperformers in three-person teams for the next phase of the semester. This procedure is not necessarily punitive; it is entirely possible that the underperformers were overshadowed by strong personalities in their previous teams. A change of partners may enable them to take more control in the remaining projects. Though this process is not always followed, the opportunity for reorganizing the teams after the second, or even third project, allows for such a possibility.

As mentioned earlier, the final project phase (during the last six to seven weeks) entails gathering five to six smaller teams into a single megateam. In some semesters, the entire student enrollment is reorganized into megateams, regardless of their prior small team assignments. However, each smaller team retains their Mindstorms®-based kits, such that there are five to six RCX control units available for their use. Thus, the final project allows for distributed computing, collaborative robotics, or industrial automation principles to be explored.

**LEGO Kit Management**

The Lego Mindstorm kits, including RCX, motors, sensors, and Lego parts, can contain as many as 1000 separate items. The EGR 286 course instructors have elected to loan (basically, issue) the entire kit to the small teams. This method is preferred because the students are already assessed a significant engineering labs fee ($40 per credit hour). Additionally, the faculty wished to assess the durability of the RCX computers (this issue is discussed later). In conjunction with the loan policy, a “lab breakage fee” procedure is followed, similar to that of a chemistry class: If a student loses or breaks more than $20 worth of the kit, then that student is assessed the balance via NAU’s financial computer records system, towards next semester’s registration.

A procedure for student self-checking of the kits has been developed, which has resulted in relatively few problems are associated with the kit returns and missing or damaged parts. As part of the mid-semester team reassignments, the instructors require the teams to inventory their kits against their kits’ inventory sheets. The team signs a ‘verification sheet,’ citing which components are bad or missing from their kit. As long as the parts are insignificant (small components), the instructors and TAs will re-stock the kits without charge to the team turning in that kit. These kits are then re-issued to new teams, with the previous team’s inventory sheet.

This kit-checking process has had a couple of interesting learning aspects:

- The teams learn self-reliance and deadlines. They associate these deadlines with real costs and outcomes.
- The students understand integrity and ethical behavior. There has been several (rare) instances of discrepancies between the team kit exchange (inventory mismatches). In all cases, there was at least one student in one team or the other who confessed that the team did not actually check the kits, but simply signed off on the verification sheet without examination of the kit contents. In other words: the students themselves monitor their own ethical behavior.

From a course management point of view: It is much more efficient to have each team check their own kits than to have an instructor check 20 kits or more on their own. An added benefit: Each kit is checked twice as part of the exchange: Once by the checking-in team, and once by the new checking-out team.

I. Durability

The Lego RCX have proven to be very durable, given that they are used continuously each semester, and even in summers—NAU has a summer orientation course for high school students which use the kits. Most of 26 kits (and associated RCX controllers) were purchased in the summer of 2004, with an additional 12 kits purchased in 2006 and 2007. As of this publication date, only five RCX computers have exhibited defects, requiring replacement. These failures are:

- A defective start button
- A failed IR emitter (2)
- An inability to retain firmware (2)

This failure rate of 13% over a 4-year period (or an average 3.25% annual failure rate) is considered acceptable, especially in light of the fact that these RCX systems are used quite heavily. Their use includes somewhat physically abusive and creative applications. For example, at least one ‘robot wars’ style project is accomplished each semester, where the robots ram, push, and drop onto other robots, all containing the RCX computers. Unless the RCX casing is obviously, physically, damaged, the students are not charged for the occasional RCX breakdown while under their ‘care.’

### Facilities

The Engineering Programs facility underwent renovation in 2005-2006. Inherent in the expansion are two large and connected classroom spaces (Figure 4). This space is...
dedicated primarily to the freshman and D4P course offerings. The EGR 286 kits and related equipment (such as computers) are organized in this new space, where the furniture has been selected to support that educational mission. The classrooms can be divided by the large, insulated, roll-up doors, so that the rooms can provide for joined or separated activities as needed.

One consideration with using so many kits in the class is how the students use them as part of their academic life. Students need a place to store their kits in the building, as a central location for all of the individuals to access throughout the week. Thus, a set of deep lockers were installed for this purpose in the D4P classrooms (Figure 4), back/right corner.

FIGURE 4. D4P DEDICATED CLASSROOMS. KIT LOCKERS ARE SEEN THROUGH WINDOW, IN BACK CORNER OF FAR ROOM.

As all students are required to understand and program in NQC for their robots, 32 basic laptops were purchased to accommodate the EGR 286 class. A Bretford 30-laptop storage/charging cabinet was obtained to enable recharging of the laptops when not in use (Figure 5). The charging cycles are alternating between sets of the laptops, to enable them to recharge from a single 110V outlet, without overloading the amperage rating of the circuit. The laptops by necessity were basic and inexpensive, the primary requirement being they were wireless-enabled and could run on a single charge for at least 4 hours. The first requirement was so that a dedicated wireless network could be used by the students in the D4P rooms, with up to 26 simultaneous connections not overly taxing the network. The battery power requirement enabled the laptops be used without external power for the duration of any lecture/recitation period. This requirement is proving to be a challenge this past year, as the course is now offered twice per semester, due to increased engineering enrollments.

The laptops are “checked out” by the teams as part of their recitation and general design and construction processes. Each student who checks out a laptop typically hands over their student identification card. The card is placed in the slot where the laptop is stored, thus enabling the instructor or TA to track down a tardy laptop. These laptops are checked out both during class periods and during non-classroom “office hours” set up by the student TA’s. These office hours are conducted in one of the two dedicated D4P rooms, so that the students are able to ‘study’ outside of class time. As NQC is available freely on the internet, the students also can install their NQC environment (“Bricx” is the preferred choice) on their own laptops.

FIGURE 5. LAPTOP CHARGING AND STORAGE CABINET.

PEER EVALUATIONS AND DISTANCE EDUCATION ENVIRONMENT

As presented earlier, the team grades are allocated to individual students based on a combination of student peer evaluations and instructor assessments. When class sizes were smaller, the student peer evaluations were collected via emails from the individual students and manually entered into a spreadsheet by the instructors. However, larger class sizes over the years necessitated development of an automated, web-based evaluation tool. The tool was completed for use in Fall 2002. Error! Bookmark not defined. The core of the peer evaluation system is a set of CGI programs written in the Perl language and running under the Unix operating system on a web server. The system is secure and limits access to validated users only. Data is transferred between the peer evaluation system and Excel grading spreadsheets.

This system was created separately from the fledgling distance education program at NAU. Thus, the peer evaluation tool was a stand-alone system. Today, NAU is the leader of the distance education course infrastructure for Arizona and as such, has extensive, commercially available web tools available. NAU is encouraging all its on-campus programs to access and use their latest web-based environment, WebCT Vista. This author began porting various EGR 286 materials to WebCT Vista in 2006, to the
Nevertheless, the WebCT Vista system is not currently capable to support the peer evaluation system in an integrated manner. The primary reason is that this education-oriented web environment has strict security on how a student’s login can access the educational database for his class. That is: A student cannot access, alter, nor input information into another student’s educational database. This security structure is vital for privacy and course grades, but is a problem when an assessment or quiz tool needs to access the class roster so that a student can accomplish a peer evaluation on a fellow teammate’s performance for a project.

The solution at this date is to simply access the old CGI computer tool via a web link in the WebCT Vista environment. One advantage of this procedure is that the students no longer need to type in an URL address, separate from their course web page, in order to access the stand-alone peer evaluation tool. They can now access the peer evaluation system via the same EGR 286 WebCT Vista webpage that they have been accessing for all their other course materials. A long-term goal is to develop a wholly WebCT Vista-based survey tool to replace this peer evaluation system. In this manner, two separate network systems would no longer need to be maintained for a single course.

A second problem with the use of WebCT Vista in this team-oriented course is the sharing of files between the individuals on the team. Individual students each have their own file system through the web-based environment, but cannot have a “shared” directory available in the system for their assigned teammates. This problem is again associated with the security limitations of WebCT Vista. As the projects are very computer-oriented, the EGR 286 instructors set up a separate shared folder system for the student teams, manually creating restricted access for each team member’s allocated file system ‘by hand’ or through scripts run on the network server. The file server is run and maintained independently from WebCT Vista. Again, a future goal is to integrate a group-oriented file system capability in WebCT Vista, thus eliminating the need for managing separate network systems for a single course.

CONCLUSIONS

Presented was an overview of the management of a large-enrollment, robotics-oriented design course at the sophomore level in engineering. Mindstorm kits and accessories are the basic kits used by the student teams, and nearly all informational materials are presented online through web-based systems. The management of these kits, the classroom facilities, and the web-based systems requires planning and coordination by the course instructors. However, with the system established as described in this document, the class runs smoothly. Students gain both education and experience in the management of complex design, through both the course content and the management of the class itself.

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