The Design4Practice Sophomore Design Course: Adapting to a Changing Academic Environment

John T. Tester, Jerry Hatfield
Northern Arizona University

Abstract – At Northern Arizona University, an interdisciplinary sophomore design course – EGR 286 – has undergone a fundamental shift in its innovative and award-winning course structure. This shift is funded in part through a Hewlett Foundation-supported development effort to encourage recruitment and retention of engineering students, with an emphasis on under-represented student populations. This recruiting and retention effort is emphasized in light of historically declining enrollments on the campus as well as in some engineering departments. The course revitalization is centered on enabling more direct student participation in design projects. It begins with two-person design teams that design, build and test weekly projects involving LEGO® parts, sensors, and the Robotic Command eXplorer (RCX). The course progresses in the semester to finally encompass larger design teams of fourteen students, with each team designing a complex, autonomous, robotic-styled system. This revision was to enable a more flexible mix of engineering student majors (Mechanical, Electrical, Civil and Environmental), as some departments had different enrollments for each semester. Furthermore, the philosophy shifted from a primarily project management to a more technical design/build/test approach to design education. The students learn both technical and team skills incrementally by accomplishing new designs each week for nine weeks in teams of two to four students. In the final six weeks, the smaller teams are merged into a larger team of 14-20 students, such that they may then be better able to design a much more complex robotic system design. We detail the course restructuring, which includes the small-projects concept to build knowledge, the course management issues for the college, and the material costs incurred.

Index Terms –Student retention, design education, engineering education.

Introduction

The College of Engineering and Natural Sciences (CENS) at Northern Arizona University (NAU) is renovating the way it recruits, educates and graduates engineering students. With the aid of the William and Flora Hewlett Foundation, CENS is actively assessing its regional recruitment resources for incoming freshmen, as well as restructuring its courses to excite and encourage currently-enrolled students to stay in engineering. NAU is the smallest of three Arizona universities offering undergraduate engineering education programs. While the larger University of Arizona and Arizona State University (ASU) enrollments have increased since 1998, NAU CENS enrollments in engineering has remained constant.[1] CENS Engineering personnel applied for and received a five-year grant under the William and Flora Hewlett Foundation Engineering Schools of the West Initiative to aid in increasing ongoing enrollment.

There are basically two ways to increase enrollment (and thereby inferred, graduations) of engineering students: 1) increase the numbers of entering freshmen and transfer students, and 2) increase retention of currently-enrolled students. The topic of this paper is primarily associated with retention of sophomore engineering students.

The “Design4Practice,” or “D4P,” curriculum is a series of innovative undergraduate classes which involve active learning laboratories for the students in each of their freshman, sophomore, junior and senior years. This program received the 1999 Boeing Outstanding Educator Award, in recognition of its quality and effectiveness in providing a well-rounded engineering design education.

The program objectives were developed in response to the call by industry 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 in design and in teaming.

Each D4P course builds on the previous design course with the threading of topical design content from course to course. The courses are team-taught by faculty and local engineering practitioners who are experienced in engineering design. The sophomore design course, EGR 286, is the course where students fully integrate their current level of engineering education with a semester-long, team-based design activity. EGR 286 was and is currently the cornerstone of the Engineering undergraduate design curriculum. The use of a semester-long project was believed for years to be the primary means by which to immerse the students in an early, engineering practice-oriented design process.

In the three-credit-hour EGR 286 course, students experience the process of engineering design by actively learning and practicing design within a simulated corporate environment – an organization which develops and builds electro-mechanical systems for various external clients. The clients in some semesters may be actual external partners, or may be fictitious clients created by the faculty. These ‘robots’ are guided vehicles with integrated electrical and mechanical systems controlled by users via a software interface.

The old EGR 286 teaching format consisted of having large teams with mixed disciplines assigned to a single design project for the entire 15-week semester. The design teams were about 20-25 students in size, each comprised of Electrical, Mechanical, Civil, Environmental and Computer Engineering students. The proportion of these students varied with each semester, but typically the largest proportion of students was Mechanical Engineering students, followed by any combination of the remaining disciplines. The electrical circuits are designed and built by the Electrical Engineering students, the software by the Computer Science students, and the hardware by the Mechanical, Civil and Environmental engineering students. The latter three student groups were combined, as their educational backgrounds were similar in their sophomore year.

The Use of Legos® for Prototyping

Legos were used in both the old and new course format for a very simple reason: These literal building blocks allow for physical prototyping without the student needing to have great mechanical skills. Another equally important reason: The educational institution does not need extensive manufacturing facilities for constructing prototypes if Legos are the primary mechanical prototyping media. It should be noted here that, in the old course format, some limited custom parts were

allowed to be fabricated. Typically, student teams preferred to stretch the ‘limited’ definition, constructing much of the robotic system out of fabricated parts (example in Figure 1); such preferences typically earned them unknown difficulties during the design process.

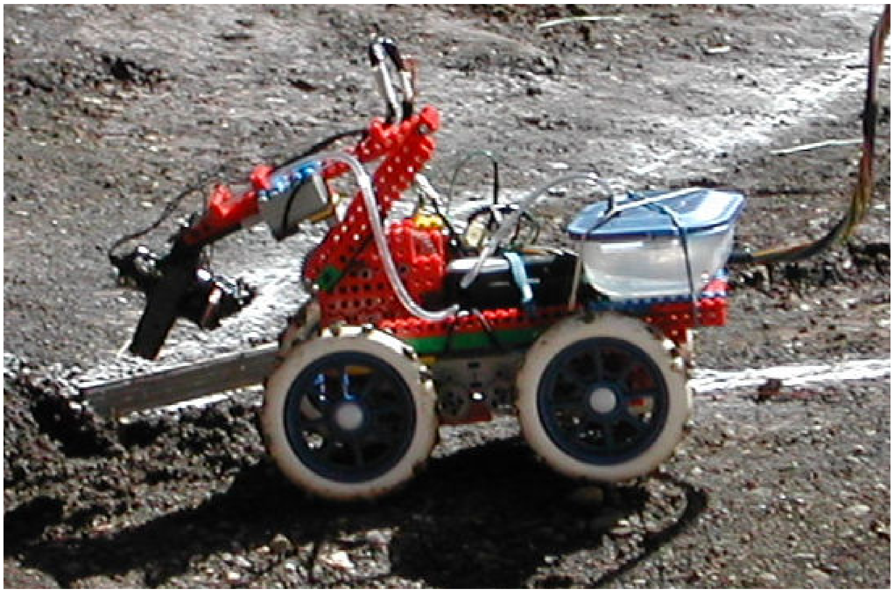

Figure 1. Spring 2002 EGR 286 Design—A water-sampling robot. The tether behind the robot is attached to a separate PC, running C++ software.

Using Legos for physical prototyping is very prominent in undergraduate engineering education. [2, 3, 4]. The use of Legos allows for 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. [5, 6] 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. [7, 8] Based upon these prior success cases, the EGR 286 revision incorporated the RCX as a controller and eliminated the use of custom circuit prototyping. The latter was a source of serious difficulty for the course, due to a frequent imbalance of students with basic circuits education in the EGR 286 course.

Impetus for Change: The Changing Environment

In spite of the advantages of a single, semester-long project, the faculty began to understand some disadvantages with the core course structure. Even though the D4P program was acknowledged as “innovative,” the College of Engineering and Technology (now the College of Engineering and Natural Sciences, or CENS), was nevertheless still experiencing the typical retention problems of engineering students leaving the program. The retention rate of students after the first two years was only about 60%, which was typical for many engineering programs across the country. CENS Engineering faculty desired to retain more students by revisiting the core D4P courses. This effort resulted in revitalization of the EGR 286 course.

The EGR 286 sophomore course was tackled instead of the freshman (introductory engineering) EGR 186 course for several practical reasons. The first reason was due to the nature of the Arizona credit transfer arrangement for engineering freshman introductory courses. The freshman course, in

its current format, was already approved for equivalent credit at the other major engineering colleges in Arizona. Revising that course would require laborious and intensive negotiations with at least two other four-year universities, plus numerous other community colleges. Changing the sophomore EGR 286 would not require the same cross-institutional agreements.

Another primary reason to address EGR 286 was based upon its great potential to stimulate external interest in the NAU Engineering program from regional community colleges and high schools. The course used computer-controlled, Legos©-based systems as the realization for the student designs. Use of these systems, plus terming the projects as “robotics” or “automated vehicles,” stimulated young minds to the potential of engineering as a viable option for their future undergraduate education.[9] The concept envisioned by the faculty was to create smaller modules of the course that could be taught to daily or summer weekly outreach sessions, containing high school students or early community college students. Yet, the old format of the EGR 286 class was not suitable for “exporting” to community colleges or high schools. This lack of suitability was due to the fact that the course was currently structured to examine, in depth, all the nuances of a 15-week design project on one single, complex, design task.

In the old EGR 286 course organization, the (approximately 50-70) students were divided into three business “divisions,” each having three smaller “teams” of roughly seven students each. The divisions operated independently on the same project, which lead to a natural competition among the divisions to create the “best” design. The downside to that approach was that, due to the uneven enrollments, some semesters would have a dearth of certain disciplines verses other semesters. Assigning design tasks, such as circuit design to only electrical engineering students, and software design to Computer Science students, was becoming more difficult each year. As an example: In 2002, EGR 2002 had only 6 Electrical Engineering students in the class, thus making it impossible to divide their expertise across all the nine teams in the course, under its current pedagogical concept.

The last administrative wrench was tossed into the mix when the Computer Science department reworked its curriculum in Spring 2004 and dropped EGR 286 as a required sophomore class. Assigning programming to only Computer Science students became impossible at that point. However, it became an opportunity for the Civil and Environmental Engineering students to learn programming, as they did not have an opportunity to learn it in their current plan of study; if all students were required to participate in the programming of their robots, then these students would have an opportunity to learn as well.

In the student post-class surveys, it was also becoming evident that the 21-person divisions allowed for significant non-participation by many students as the semester progressed. Though the participation of the students were measured with an anonymous student-generated “peer review,” the problem persisted. Not only were students managing to go through the class with less contribution than other students, but the outstanding students were becoming discouraged by their less-performing teammates. It was also noted that not all the non-performers were lazy or uninspired; many were timid or unaggressive students in large groups. It was particularly observed by the faculty that Native American students were especially not forthcoming in the class; the faculty wished to create a technical environment so that they would have greater comfort in contributing to team efforts.

The faculty also observed that many of the students were not at an appropriate technical level for many of the sensors, motor control, and programming issues that were required to be solved for some of the system design concepts they proposed during the course. Since teamwork and program management was heavily emphasized in the course, the technical engineering education was regulated to a series of two to four workshops during the semester. The faculty realized that these limited workshops were both insufficient to provide depth of knowledge to the students and also insufficient to provide interest to the majority of all students in the course.

Revitalizing the sophomore class also was a necessity due to the workload upon the faculty who taught it. It was oriented towards mostly project management of the design process. Though a necessary aspect of the education process, intensive project management in a one-semester course required the use of large, multiple reports from multiple design teams. The correction and grading of these reports, in the current context of the EGR 286 offering, took a heavy toll on the responsible faculty, many of which also taught the other freshman, junior and senior design courses as well.

Course Enhancements

The course was changed to accommodate several objectives:

1. Encourage continued enrollment in the engineering program.
2. Incorporate a small team design format.
3. Technical knowledge is transferred to students in an active-learning format.
4. The technical knowledge provided to the students directly supports the large team project.
5. Continue oral presentations required of all students.
6. Continue written design report requirements.
7. Incorporate project management issues, but not as the top priority in the class.
8. Allow for student teaching assistants (TAs) to assist in the active learning process.

In support of the above objectives, the overall course progression was designed as is schematically shown in Figure 2. The progression can be summarized as:

1. The first nine to ten weeks of the semester would involve teams of two students each.
2. The small teams would work on *weekly* "short projects" which address specific technical issues of the larger project to come.
3. The course would culminate in a complex robotic project, requiring the efforts of roughly 12 to 15 students in a single "megateam."
4. This "large project" (also known as the "final design project") would only be addressed in the last five to six weeks of the semester.

By working in smaller teams at the start of the semester, individuals would 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 projects 6 and 7; 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.

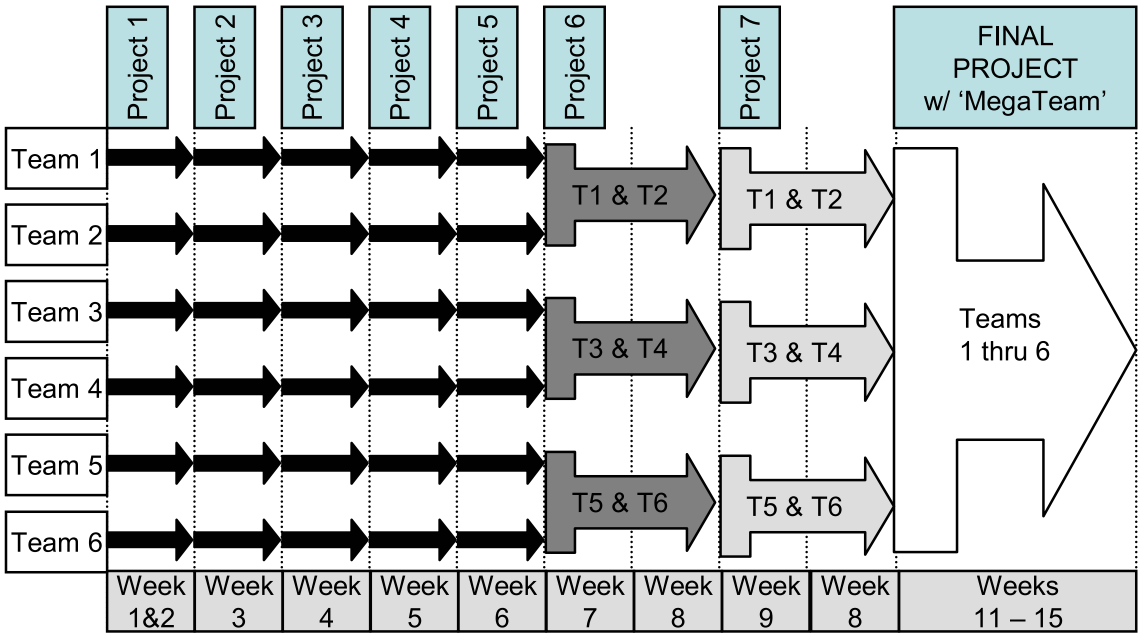

Figure 2. Course Progression. Note: Typically, 12 or more teams are in one class.

The class would still use Legos as the basis for mechanical design. As presented earlier, RCX programming module would be the controller for the robotic designs (previously, all software was PC-based). *All* students would be required to learn both RoboLab and NQC in the short projects as well as in the final project. 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, more than one) RCX in its controlling system.

Small Team Format

There are multiple, two-person teams created; these teams may be considered as "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 arrivals, limits on equipment resources), several three-person teams are also allowed. With only two students (on average) in a team, no effective self-evaluation "peer review" process is possible.[10] The team's grade for a weekly project is literally that grade, for both students, though the instructor had the leeway to alter an individual student's grade if he or she were not present for a given week for a particular short project.

Some projects were sufficiently complex to require two weeks to complete. These projects were shifted towards the end of the first phase of the semester (the 10-week period). They also may be duo-teamed; that is, two small teams were required to work together to accomplish the project. This method introduced the students gradually to the concept of working in yet larger teams.

At the eleven week point in the semester, five to six small teams were grouped into megateams. These megateams were required to work on the final project, cumulating after five more weeks. One advantage of this method was that the students, by this time, all understood that they must *immediately* begin on the final project, as they had experience that technical design requires a paced

effort, and not a last minute one. With larger numbers of students working together, an anonymous peer review evaluation process was in effect within each megateam for the remainder of the semester. This peer review process used a web-based program to insure its ease of use. [10]

Active-learning Format

The technical knowledge for the sophomore design class was necessarily basic, due to having a cross-section of mechanical, electrical, civil and environmental engineers. Nevertheless, basic education was provided for areas of sensors, motor control, mechanical design and programming. Each weekly project started on a Monday and ended on a Friday with a demonstration of their robot. The robot was built mostly during the class hours, though the teams were allowed to take the materials home with them for additional work time.

The class format is structured such that there are three lecture hours and two "recitation" hours. The lecture hours are required for attendance by the students; during these periods, the instructors provide the problem statement, present technical information, and some examples that relate to the problem at hand. At the recitation sessions (following two of the class periods each week), the students are to discuss their upcoming designs, implement their design ideas, and test their designs. Instructors and student TAs are available to assist the students with problems they may have during this process; most of the problems arising are associated with programming issues, as most of these students are introduced to programming for the first time in this class.

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:

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).

For illustration: The second short project listed was a kinematics-styled, "four-bar" project.

Oral Presentations, Written Reports, and Project Management

In the prior EGR 286 format, at least one oral presentation was required of each student. This presentation was accomplished in the context of a three-stage design process: Conceptual, detailed, and final design phases. This format was retained, but the three presentations were accomplished during the final project weeks, one per week (or two, depending upon the academic holiday calendar).

Written reports were required from each megateam after each presentation in the old course format. These reports were large (often exceeding 20 pages in length) and difficult to grade; also, with a large timeframe between presentations of at least 4 weeks, the students often did not learn from the previous report's grading results. For the new format, each small team turned in a 2-page design summary report for each short project. As a result, the grading process was a more steady grading

workload for the instructors, and provide more immediate feedback to the students for the next project.

The practices of planning, resource allocation, and scheduling were a major component of the former EGR 286 course format, throughout the entire semester. However, with the emphasis on providing more complete technical information to the students in the new format, the project management issues were de-emphasized during the first nine to ten weeks for the short projects. This topic was addressed in the final project, but not as in-depth as with the old course format.

Student TAs

In the past, student TAs were never allocated to this course, even though up to seventy students could be in a single classroom for active learning sessions. The new course format insisted upon inclusion of such assistance; the Hewlett Foundation funds, plus other undergraduate research funds, allowed for a trial of using student TAs. Their inclusion proved to be a tremendous advantage. Not only did they allow for more organized recitation sessions, but the enrolled students would be far more comfortable in revealing their difficulties to senior students, rather than having to admit their failings to the instructors. Student TAs also set aside regular office hours specifically to assist students in the EGR 286 technical topics. The drawback: The TAs began to see the students more frequently on an individual basis than the instructors, such that the instructors lost some of the direct contact with many students.

Course Management Issues

The current structure allows for the dedication of three faculty assigned to the class. However, the goal is to make the offering more "standardized," such that by 2006, one faculty with several student TAs can teach the course. Part of this objective will be satisfied by documenting a series of both final projects and standard weekly projects. An instructor can select a final project, then choose five to seven short projects which will support that final project. Accumulating short projects is similar to the activities which produced the fine laboratory manual offered by Wang. [11] The authors would have chosen this manual as a required text in the new course revision, but for the fact that EGR 286 needed to be offered with both RoboLab and NQC for curricular reasons; Wang's manual is only offered with RoboLab examples. Additionally, the authors needed a series of larger, more complex projects as a database from which to select their final projects.

Another reason for documenting the short and final projects is to create the potential for "exporting" the course format to regional community colleges. These institutions, once offering the sophomore design course, in a similar format, can then better coordinate future two-year engineering credit transfers with NAU's Engineering Program. The projects database can also be used as a resource for short-format educational venues, such as for summer high school outreach workshops or secondary teacher science/computer/engineering training workshops. This concept fits well into the recruitment activities funded in part by the Hewlett Foundation grant effort.

Team organization and management is a major undertaking at the start of the semester. The goal is to have two-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 two-person teams, creating three-person

teams. This "long short-project" has other advantages as well—it allows for logistical time to enable the issue of course materials, primarily that of the Lego kits to the teams.

After the fourth short project, the teams are reorganized again into new two-person teams. This shuffling of students is accomplished so that the students have a new teammate for the remaining projects. The procedure also enables the instructors to place observed underperformers in the same two-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.

As mentioned earlier, the final project phase (during the last five to six weeks) entails collecting five to six teams into a single megateam. If a student had the misfortune to be paired with a difficult partner, this larger grouping enables the student to have more partners for interaction during the last of the semester. 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.

At this point, is appropriate to discuss Lego kit distribution and how various universities handle such issues. The kits, including RCX, motors, sensors, and Lego parts, can number as many as 1000 parts. Wang et. al. covers this topic well; basically, there are four ways in which a Legos-intensive course can handle the logistics: [12]

1. Require students purchase kits.
2. Maintain dedicated laboratory for kits and robot construction.
3. Loan or rent entire kits to students.
4. Loan or rent core components to students, and require students to buy basic Lego parts separately.

There are advantages and disadvantages to each; Wang et. al. noted that their institution (University of Nevada-Reno) uses the fourth method, renting out the RCX, sensors and motors, while the students buy recommended kits. In this manner, they do not need to inventory the many small parts on their return at the end of the semester.

The authors, at this current stage of course revision, 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 wish to assess the durability of the RCX devices—these devices have been still relatively untried on a large scale in the engineering program courses. In conjunction with the loan policy, a "lab breakage fee" procedure is followed, similar to that of a chemistry class: If a student looses 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. The first semester with the new course changes resulted in relatively few logistical problems associated with kit returns. However, the student TAs spent approximately 20 manhours checking 26 complete kits.

The NAU Engineering Program has an additional asset coming online soon: The Engineering building facility has been undergoing renovation in 2004 and will be ready for occupancy in 2006. Inherent in the planned expansion are two large design spaces, one of which will be dedicated primarily to the EGR 286 course offering. Thus, the kits and related equipment (such as computers) will be organized in a new facility, where the furniture has been specifically selected to support that educational mission.

As all students are required to understand and program in RoboLab and NQC, computing facilities must be available for them as part of the recitation experience. This requirement results in a need for at least 26 or more PCs available for use, given there are at least 52 small teams in any given semester. The authors are fortunate to have several computing rooms in the temporary educational facility immediately available to the instructional room; as discussed previously, the new engineering facility will have dedicated rooms for this purpose, also nearby. In a university environment where departments are separately housed, the dispersion of facilities could be a problem for this type of course format.

Costs

The baseline Lego kit used was the Mindstorms Invention kit, retailing at $299 per kit. This kit includes the RCX, 2 motors, 2 touch sensors, one light sensor, and 717 Lego elements ('bricks' and shaped parts). Both the short and final projects also required the use of an additional motor, light sensor, and two rotation (angle) sensors. The total cost per issued kit to each short-project team was thus $380. With 26 such teams (as present in the first revised course offering), plus four additional kits for use by the TAs and instructors during the semester, the capital outlay was thus $11,400. Of note is that this cost is essentially all "start-up" cost, as these kits will be reused (given no breakage). If breakage or loss occurs, the students are required to pay a "breakage fee" proportionate to the loss incurred by their 2-person short project team.

The high initial investment is certainly viewed as an obstacle for implementing on a large scale at other universities. In particular, high schools and community colleges will have difficulty in such purchases; in such cases, perhaps one of the other kit management techniques discussed earlier is a better alternative.

RoboLab was required for the first several short projects, and was optional for the final project; its site license cost was $80. The site license for that software was $80. NQC has a public domain license and thus had no cost. The faculty chose to use the BricX programming environment (also public domain) for that programming language.[13]

Miscellaneous items used in the short and final project demonstrations also added to the course offering costs. In particular, the use of "whiteboard" material (wallboard used in place of chalkboard) became prominent, as that material gave a good contrast to black electrical tape for line-following projects.

Assessment

The changes in the course offering include assessment procedures developed by the authors and with assistance from a research associate for the Center for Science Teaching and Learning at NAU. Several assessment instruments were created, including:

- Course-specific assessment surveys
- Student interviews
- A "Student skills/aptitude self-assessment" survey

As the primary purpose of this paper is to present in detail the course changes, the details of the assessment process are documented elsewhere.[14] The results from this ongoing assessment process are to, at a minimum, understand whether or not the new course format stimulates the students' enthusiasm for engineering and thus encourages them to stay in the rigorous engineering curriculum. Additionally, a newly implemented computer tracking system at NAU has enabled the authors to query student histories and determine whether there will be an improved retention of students who take this class. Since the new course revisions were implemented only in Fall of 2004 for this sophomore class, it is too early to examine graduation rates of those students who have taken the new course. The authors acknowledge in advance that a future improvement of graduation rates from computer data will not be direct evidence that the EGR 286 course improvements were the impetus for such increases. However, such data can be combined with the historical assessment data mentioned earlier to assist in understanding how student come to stay and graduate in engineering at NAU.

Conclusions

The revised course format will be further revised in the coming semester. Using small teams at the start and improving technical content have shown positive results from the assessment results. [14] However, some improvements are still necessary. The course revisions are new; therefore, the faculty must repeat the new format so that more timely presentation of *all* material becomes routine.

One future effort planned by the authors will be to offer a summer faculty workshop for all NAU CENS faculty, high school, and community college instructors. This workshop, anticipated to be 3 to 5 days in length, will be offered for the incoming student TAs as well. This effort will enable a greater dissemination of this course content to more instructors at both the college and secondary school level.

At least one of the short projects from the course plan will be used for a high school student summer camp, organized by the CENS Multi-cultural Engineering Program office. This camp is for regional students interested in engineering and is targeted for underrepresented groups in engineering enrollments, such as minorities, women and first-generation college students.

Acknowledgements

This research was accomplished under a grant by the William and Flora Hewlett Foundation, as part of the Engineering Schools of the West initiative. The NAU Hooper Undergraduate Research Assistantship Program also contributed to this research effort.

Bibliographic Information

[1] ASEE Profiles for Engineering Colleges – **http://www.asee.org/publications/colleges**

[2]Jolley, W., Rencis, J., Cobb, E. and Hagglund, R. "Incorporating a LEGO fourbar mechanism project in undergraduate dynamics" Proceedings, 32nd ASEE/IEEE Frontiers in Education Conference, Boston, MA, November 2002.
[3] Flikkema, P. "Learning Embedded and Real-time systems via low-cost mobile robots," Proceedings, ASEE Annual conference and exhibition, session 1332, 2001.
[4] Wang, E. L., LaCombe, J., and Rogers, C., "Using LEGO® Bricks to Conduct Engineering Experiments," Proceedings, ASEE Annual conference and exhibition, session 2756, 2004.
[5] Goff, M. and Vernon, M. "Using LEGO RCX bricks as the platform for interdisciplinary design projects"proceedings of the ASEE Annual conference and exhibition, session 3425, 2001.
[6] Shih, A. and Hudspeth, M. "Using the LEGO robotics kit as a teaching tool in a project-based freshmen course" proceedings of the ASEE Annual conference and exhibition, session 1353, 2001.
[7] . Campbell, M.I. "Teaching machine design through product emulation" proceedings of the ASEE Annual conference and exhibition, session 2366, 2002.
[8] Moor, S.S., Piergivanni, P., and Keyser, D. "Design-build-test: flexible process control kits for the classroom," Proceedings, ASEE Annual conference and exhibition, session 1526, 2003.
[9] Pomalaza-Raez, C., Groff, B. H., "Retention 101: Where robots go…Students Follow," Journal of Engineering Education, Jan 2003, pp. 85-90.
[10] Hatfield, Jerry M.; Tester, John T., Assessing individual performance within a team using peer evaluations, Proceedings, ASEE 2004 Annual Conference and Exposition, Salt Lake City, UT, Jun 20-23 2004, p 711-719.
[11] Wang. E. L., Engineering with LEGO Bricks, College House Books, Knoxville, TN, 2002.
[12] Wang, E. L., LaCombe, J., and Rogers, C., "Using LEGO® Bricks to Conduct Engineering Experiments," Proceedings, ASEE Annual conference and exhibition, session 2756, 2004.
[13] http://bricxcc.sourceforge.net/
[14] Tester, John T., Haden, Carol, Hatfield, Jerry M.; "Developing Recruitment and Retention Strategies through "Design4Practice" Curriculum Enhancements," Proceedings, ASEE 2005 Annual Conference and Exposition, Indianapolis, IN, Jun 2005

Biographical Information

JOHN TESTER is an Associate Professor of Mechanical Engineering at Northern Arizona University. He received his doctorate in Industrial & Systems Engineering at Virginia Tech. Prior to his academic career, he was a Mechanical Engineer at the telecommunications firm, Amtech Systems; he also served as an engineering officer in the U.S. Air Force. His interests include design, advanced manufacturing, renewable energy and engineering education.

JERRY HATFIELD is an Associate Professor of Electrical Engineering at Northern Arizona University. He is a graduate of the University of California (BSEE) and of the University of Southern California (MBA) and is a registered professional engineer. His areas of interest include freshman programs, multi-disciplinary design, computer aided instruction and testing, computer aided instrumentation systems, and analog and digital circuit design.