Project-Based Learning in a Freshman Engineering Course: University – High School Partnership

Thomas C. Piechota[1], David E. James[1], and Brian Gauthier [2]
[1]University of Nevada, Las Vegas/[2]Advanced Technologies Academy

Abstract
The use of project-based learning with student teams is presented for a freshman-level *Introduction to Engineering Design* course taught to Civil and Mechanical Engineering students along with junior-level High School students. A project-based approach exposes the students to the concepts and processes involved in engineering design. Approximately ½ of the course is hands-on activities (using physical and computer models) where the students are able to apply fundamental engineering concepts to real life activities. Examples include forces on structures demonstrated through bridge construction, and fatigue of materials through failure analysis of common household items. All activities are performed in teams of three to four students. Team-building concepts are used to illustrate the critical issues of team-work. The other ½ of the course is devoted to steps in the engineering design process. Students demonstrate mastery of the material at semester's end by working on a team design project. Each team member has assigned tasks and is held accountable for that portion of the design project. All students are responsible for ensuring that the final project is an integrated work that represents the team effort. Teams are required to build a physical model, complete a technical report and orally present their design.

Introduction
The curriculum of typical freshman engineering students emphasizes mathematics, physics, English, and other electives in the arts, social sciences, and/or political sciences. The role of engineers in today's society is not typically emphasized and students do not see the important role that engineers play in meeting societal needs. This paper presents a freshman engineering course that emphasizes the role of engineering in society and introduces the engineering design concept. In addition to the students at the University of Nevada, Las Vegas (UNLV), this course is also offered to junior high school students at Las Vegas Advanced Technologies Academy (A-TECH) who have sufficient mathematics and science.

To demonstrate the role of engineers, project (problem)-based learning is used in various formats. The role of project (problem)-based learning in engineering education has expanded in the past decade and now undergraduate courses at all levels are utilizing this teaching pedagogy to enhance student learning[1]. The premise of PBL is that the problem drives the learning. The students are asked to determine the information needed to solve the problem and/or project. PBL also allows the students to participate in an active, integrated, and team learning environment using open-ended or poorly-defined problems. There is a plethora of information in the literature and on the internet (e.g., http://cleo.eng.monash.edu.au/teaching/pbl-list) which has made it easier for more institutions to implement PBL. Furthermore, PBL addresses Accreditation Board of Engineering and Technology (ABET) Engineering Criteria (EC) 2000 (www.abet.org) that students demonstrate an ability function in multidisciplinary teams and communicate effectively.

This paper first summarizes the partnership between UNLV and A-TECH, and then provides an outline of the introductory engineering course and examples of student projects. Finally, the assessment tools used are provided followed by results of the high school and college students.

Partnership between UNLV and ATEC
The partnership between UNLV and A-TECH started in October of 2001 to foster the development of an early studies program for high school students interested in engineering. The A-TECH instructor's reason for initiating the contact was to expose students to real engineers and real engineering subjects in the high school classroom in hopes that students would elect to major in engineering when they matriculated at universities. The motivation for UNLV's Department of Civil and Environmental Engineering was a chance to improve UNLV's image, show students the available resources at UNLV, and to motivate local high school students to attend UNLV majoring in Civil, Electrical or Mechanical engineering. After several meetings to discuss potential classes and other interactions, it was decided that the best first course for a trial early studies engineering class for A-TECH students would be EGG 102, *Introduction to Engineering Design*, taught beginning Spring 2002. This class was selected because many engineering programs across the nation now require a general course that introduces the subject of engineering and requires a freshman design experience. An early studies credit in EGG 102 would most likely be a course that could transfer into other programs, both as general college-level credits and also as a course that would count towards the engineering requirements of many engineering degree programs.

Course Description
The course used in the partnership, EGG 102: *Introduction to Engineering Design* is a required course taught to freshman Civil, Environmental, and Mechanical Engineering students. The prerequisites for the course are *Precalculus* and *Freshman English Composition* - all A-TECH students had (or were taking) *Precalculus*. The overall course objectives are to:

1. To identify the phases of the engineering design process.
2. To design an engineering project and construct a physical model of the project.
3. To prepare a technical report for a design project and make an effective oral presentation that summarizes the project.
4. To recognize the importance of working in a design team.
5. To recognize the importance of the NSPE Code of Ethics and the responsibility of Professional Engineers.

The textbook is *Engineering by Design*[2] that is based on the five phases of the engineering design process:

1. Needs Assessment
2. Problem Formulation
3. Abstraction and Synthesis
4. Analysis
5. Implementation

PBL in the form of a design project (see next section for full description) is used to guide the students through the five phases of design. In addition, PBL is used in-class where students work on exercises that reinforce course lectures and reading (See Table 1). Individual and group assessments are used to evaluate student performance. The individual assessment is based on in class activities, homework, final exam, and the design project. A group (peer) assessment instrument is used to evaluate the contributions of the students on the final design project (see Peer Evaluation section for a complete description).

Table 1: Summary of in-class PBL activities.

In-Class Assignment	Description
1	Pre-Operative writing and oral assessment
2	Writing problem statements
3	Team building (Desert Survival)
4	Brainstorming for design project
5	Design considerations – Disposable soft drink/beer can
6	Fatigue life of Kwik-Lok closures
7	Statistics for designing a special boot
8	Identifying appropriate graphs to use
9	Problem identification
10	Brainstorming for design project
11	Duncker diagrams
12	Kepner-Tregoe analysis – Apollo 13 mission
13	Development of a balloon guidance system – Gantt Chart
14	Identifying design goals
15	Decision matrix
16	Checklist/Brainstorm
17	Problem solving – Analysis of a truss
18	Build a Bridge! – straws, pins, duct tape
19	Post- Operative writing and oral assessment

Figure 1: Student group performing in-class exercise #13 (Development of a balloon guidance system).

Engineering Design Project Description

The following description of the design project is provided to the students in the first week of classes:

> A new resort “Le Reve,” is proposed to be built on the old site of the Desert Inn. Steve Wynn (developer of the Bellagio and Mirage) has proposed that the 1.63 billion dollar project have a water-theme with a constructed lake. Near surface non-potable groundwater will be treated and serve as the water supply (you do not have to worry about the extraction or treatment of this water). Mr. Wynn is looking for ideas for the water feature that will be the centerpiece of the resort. **It is the objective of your design team to design the water feature and build a scale model that meets the following design guidelines.**

The emphasis in the project is for the 3-4 person design groups to come up with a conceptual design of the project since they have not had any of the fundamental courses (e.g., dynamics, fluid mechanics) to perform a thorough engineering design. A field trip to the Bellagio resort provided students the opportunity to see the components of a world class water feature (See Figure 1).

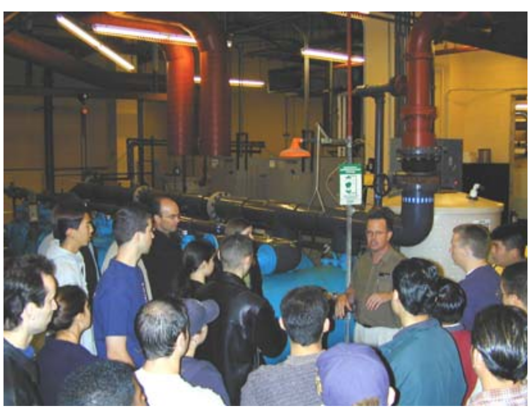

Figure 2: Photographs of field trip to the Bellagio water feature.

The **constraints** provided to the students included:

1. The sole source of energy for the system is a water spigot (hose bib) that has an operating pressure in the range 30-40 lbs/in^2 (psi)
2. The exhibit must have at least 20 water features (fountains)
3. The fountains must shoot water at least 10 cm (4 inches) high
4. The area of the model should be should fit inside a 0.61 m by 1.22 m (2 ft x 4 ft) area. You are allowed to make it smaller and irregularly shaped.
5. The area of the model should be at least 80% of the rectangular area specified above.
6. The fountain must spray the water inside the exhibit
7. The following materials will available to you at no cost; however, you will need to keep track of what you use and include the material costs in your final budget. i.e., If you used 15 tee connections (item f below), your project cost in that category is $1.50.
    a. 0.61 meter x 1.22 meter pegboard that can be used as a base ($10.00)
    b. Two Y-connections for mounting a garden hose ($1.00 each)
    c. Pressure gauge ($5.00)
    d. Adapters from garden hose connection to 1/4 " tubing ($1.50)
    e. Barb connections ($0.10 each)
    f. Elbow connections ($0.10 each)
    g. Tee connections ($0.10 each)
    h. ¼" clear tubing ($0.15 per foot)
8. No team may spend more than an extra $20.00 on the exhibit (costs other than that shown above in #7). Recycled material is permitted and does not count against the $20.00. A record of the extra project expenses, with supporting receipts, must be submitted in your final report. You will be reimbursed for the cost of materials up to $20.00.

As noted earlier, the students are given the project at the beginning of the semester and are required to submit three phases during the 15 week semester:

- **Phase 1**: Problem Definition – Thursday of Week 4, (Report Sections 1.0)
- **Phase 2**: Identification of Alternatives – Thursday of Week 6 (Report Sections 1.0, 2.0)
- **Phase 3**: Selection of Design Alternatives – Thursday of Week 8 (Report Sections 1.0, 2.0, 3.0)
- **Phase 4**: Design Analysis for Preferred Alternative – Thursday of Week 11 (Report Sections 1.0, 2.0, 3.0, 4.0)
- **Phase 5**: Presentation and Competition – Thursday of Week 14
- **Final Report Due –** Thursday of Week 14

The phasing of the project throughout the semester provides each student an opportunity to be "Lead Engineer." The Lead Engineer responsibilities included the delegation of work on each Phase, and preparation of the progress report. In addition, the groups are required to have their reports reviewed by the UNLV Engineering Writing Center prior to submittal. The different phases are handed back to the groups and it is expected that the instructor comments be addressed on the following submittal for the next phase.

The **criteria** for evaluating the projects included:

- Height of highest fountain
- Creativity of layout (site layout and plumbing need to be built)
- Creativity of water feature design
- Cost of items 7e-h (need to try to optimize the plumbing costs)
- Demonstration of model (does it function properly?)
- Engineering analysis that supports the design. Remember, someone is going to have to build the full-size version and you have to communicate your vision, rationale and design details to the constructor. Engineering analysis will include general layout and detail drawings, summary of materials, water use and pressure considerations (i.e. could get 2 foot high fountain with 30 psi with total consumption of 1.5 gallons / minute, but needed 40 psi to get 3 feet and a consumption of 2.0 gallons/minute)

Design Group Projects

As noted earlier, the groups designed and built the water feature. Figures 3 and 4 present two example projects from UNLV and A-TECH students. There was a competition where the students demonstrated their models and the instructors judged based on the evaluation criteria. In addition, the students made oral presentations (in PowerPoint) of the entire design project. By having the students build the projects, they were able to experience several concepts of fluid mechanics (e.g., headloss due to friction and fittings). In addition, they learned valuable lessons on teamwork and taking a project from paper design to a physical scale model.

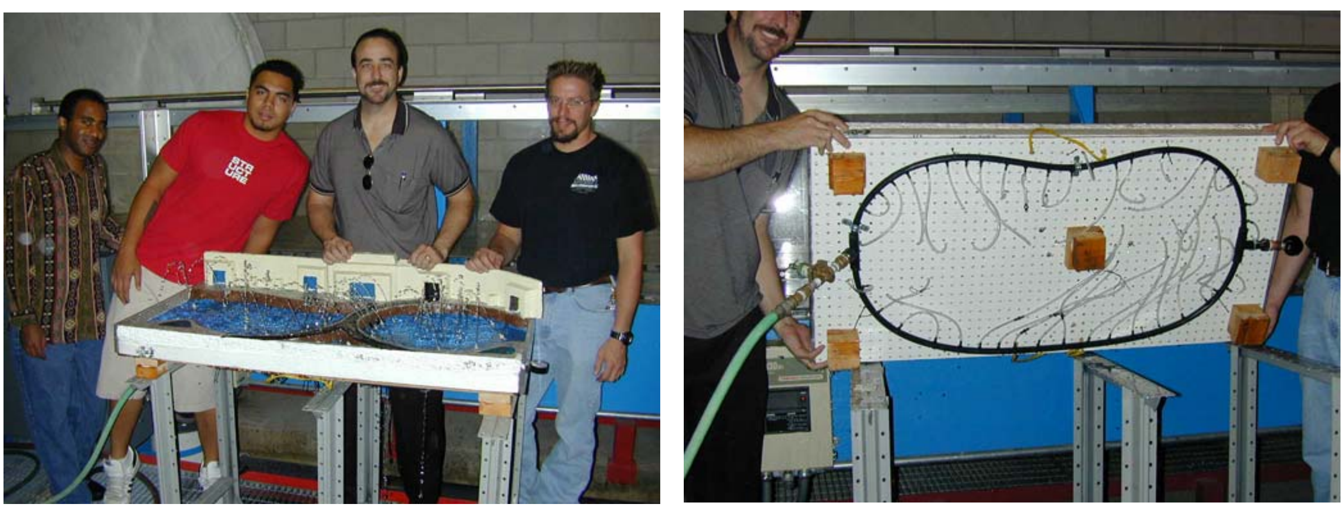

Figure 3: Example of water feature design project (UNLV - TBD Engineers).

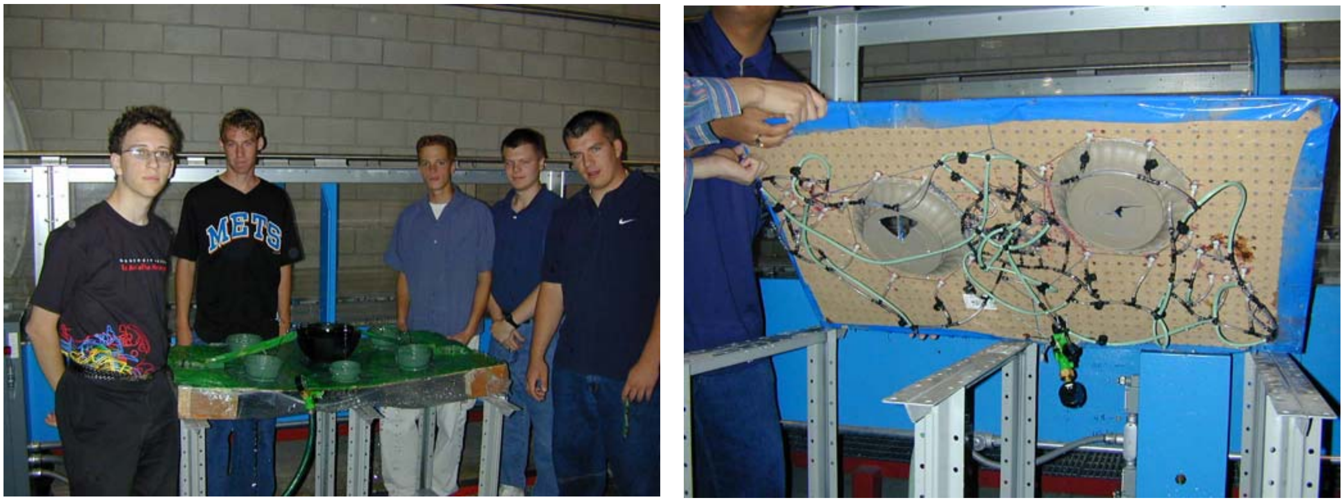

Figure 4: Example of water feature design project (A-TECH).

Peer Evaluation

The individual performance of students is assessed using a strategy developed by Felder and Brent[3]. Students are asked to provide ratings of their own individual performance and also the performance of the other team members. This provides a mechanism to assign students higher grades to students that did much of the work, and lower grades to students that did not provide satisfactory input. Figure 5 is the peer rating evaluation form used for the design project. Table 2 provides a summary of the peer assessments for all the design groups.

Table 2: Summary of peer assessments from all design groups (See Figure 5 for Peer Rating Form).

	Group #1			Group #2			Group #3				Group #4			
Student	1	2	3	1	2	3	1	2	3	4	1	2	3	4
1	5	5	5	5	5	5	6	5	5	6	6	5	6	6
2	5	5	5	6	5	5	6	5	6	6	6	5	5	6
3	5	4	5	6	5	5	6	6	6	6	5	5	5	6
4				5	5	5	6	6	6	6	2	3	3	6
5				0	0	0								

EGG 102
Peer Rating of Design Group Members

Your Name___________________________ Group Name________________

Please write the names of all your design group members, INCLUDING YOURSELF, and rate the degree to which each member fulfilled his/her responsibilities in completing the design project. **Remember to rate yourself**. The possible ratings are:

(6) EXCELLENT:	Consistently went above and beyond — carried more than his/her fair share of the load and had to help group members.
(5) VERY GOOD:	Consistently did what he/she was suppose to do, very well prepared and cooperative.
(4) SATISFACTORY:	Usually did what he/she was supposed to do, acceptably prepared and cooperative.
(3) ORDINARY:	Often did what he/she was supposed to do, minimally prepared and cooperative.
(2) MARGINAL:	Sometimes failed to show up or complete designated work, rarely prepared.
(1) DEFICIENT:	Often failed to show up or complete designated work, rarely prepared.
(0) NO SHOW:	No participation at all

These ratings should reflect each individual's level of participation and effort and sense of responsibility, not his or her academic ability.

First Name of Team Member	Rating
____________________	____________
____________________	____________
____________________	____________
____________________	____________
____________________	____________

Your signature:____

Figure 5: Peer rating form used for individual assessment of student performance on the design project.

Instructor Reflections

The partnership between UNLV and A-TECH was definitely a success and it was clear that the Junior High School students performed well in the course. It is noteworthy that the Spring 2002 cohort of A-TECH students were estimated to have average Scholastic Aptitude Test (SAT) score of about 1400-1500. The UNLV freshman engineering students have an average SAT score of 1100-1150. Noteworthy observations of no differences between A-TECH and UNLV students include:

1. **Teams:** It is important to teach students how to work in teams. Teambuilding exercises show the students the importance of sharing the responsibilities, respecting each other views, and developing consensus. The A-TECH students had an advantage of taking many courses together and were able to meet as a group more often. UNLV students all have different class, work, and family schedules and it was problematic meeting at times.
2. **Reading and lecture comprehension:** The A-TECH students were well able to comprehend the material as presented in the textbook and in lecture.
3. **Writing ability:** Although A-TECH students had not yet demonstrated that they could successfully complete a college-level freshman composition course, the overall level of writing ability demonstrated in the A-TECH section was subjectively comparable to levels of performance observed in freshman engineering students, who should have successfully passed Freshman Composition I.

Key differences observed between high school-level students and college-level students included:

1. **Motivation:** The high school students needed more external motivation from the instructors to turn in their work. The high school instructor, Mr. Gauthier, provided regular reinforcement of the need to stay on task and turn in assignments in a timely manner.
2. **Focus:** It was easier for the high school students to lose focus and become diverted in to other topics that interested them.
3. **Ability to respond to direction:** Although given abundant opportunity to respond to instructor's edits of their final reports and improve their final grades, neither team of A-TECH students followed the majority of instructions, and the second version of their final reports did not improve significantly compared to the first version.
4. **Quality of constructed prototypes:** UNLV students, many of whom are older, returning adults, had a significant advantage over A-TECH students in additional workplace skills. Some UNLV students were well-trained in the manual arts, and others had significant experience working on teams. As a result, the UNLV final design prototypes, were, as a group, superior in visual quality and engineered performance compared to the A-TECH prototypes.
5. **Group differences:** A-TECH students were probably more likely to be taking more classes together as a cohort than the UNLV students and to see each other socially on weekends. UNLV students were more likely to be in different classes; however they were more likely to be taking other classes that were intellectually demanding, such as Engineering Physics I or Calculus I.

Bibliography

1. Birch, S., 1986. Towards a Model for Problem-based Learning. *Studies in Higher Education,* 11(1), 73-82.

2. Voland, G. *Engineering by Design,* Addison Wesley, 1999.

3. Felder, R.M. and R. Brent, 2001. Effective Strategies for Cooperative Learning. *Journal of Cooperation & Collaboration in College Teaching*, 10(2), 69-75.

Biographical Information

THOMAS C. PIECHOTA, PhD, PE: Assistant Professor at the University of Nevada, Las Vegas, Department of Civil and Environmental Engineering since 1999. Areas of teaching/research interest include service-learning, water resources engineering, surface water hydrology, Geographic Information Systems (GIS) and water resource modeling, climate variability and long range streamflow forecasting.

DAVID E. JAMES, PhD, PE: Associate Professor at the University of Nevada, Las Vegas, Department of Civil and Environmental Engineering since 1990. Areas of teaching/research interests include introductory engineering, environmental engineering, water and wastewater treatment, water quality impacts to receiving water bodies and air quality.

BRIAN GAUTHIER: Science and Technology teacher at the Advanced Technologies Academy in Las Vegas for the past nine years. Classes include Technology I – III which focus on introducing students to civil, mechanical, and electrical engineering.