AC 2011-183: TEACHING ENGINEERING ANALYSIS THROUGH A STAND-ALONE JUNIOR PROJECT COURSE IN A MULTIDISCIPLINARY, PROJECT-BASED ENGINEERING PROGRAM

Pavlos George Mikellides, Arizona State University
Chen-Yuan Kuo, Arizona State University, Polytechnic campus

Teaching Engineering Analysis Through a Stand-Alone Junior Project Course in a Multidisciplinary, Project-Based Engineering Program

Abstract

Project-based learning (PBL) follows an inductive learning approach by which students are taught to undertake a materials self-study after the need has been identified through a project's context. It has been used in many senior capstone and freshman design courses to enhance students' competence in design and other outcomes required by ABET. In most engineering programs, engineering analysis is still taught mainly through sequences of traditional lecture-based courses. PBL, if adopted, usually is embedded in various courses that focus on specific technical areas to facilitate the learning process. Compared with independent project courses, such embedded PBL approach usually faces more restrictions on its open-ended nature, project selection and technical topics covered. This paper presents the results of a study on the effectiveness of teaching engineering analysis in a stand-alone project course as a part of the curriculum of a multidisciplinary undergraduate engineering program that has an independent project course in every semester.

In addition to addressing outcomes usually emphasized in other project courses, such as design, communication, teaming, etc., the critical technical issues involved in the design and trajectory of a solid propellant rocket were identified at the beginning of the project course. Then, the instructors covered the related technical topics, such as dynamics, stability and aerodynamic forces, before the students were introduced to the details of the project assignment. In this manner the approach distinguishes a portion during which topics are discussed based on the traditional predominantly theoretical instruction and a subsequent portion during which students explicitly apply such topics to the design, construction and operation of a solid rocket. The project was carefully designed such that the technical topics introduced early in the course have a direct application to the project, hence, it was required that students go through detailed analysis when they conduct design, analysis and construction of their rockets based on those topics. Tests were administered before and after the project so as to evaluate possible improvements in students' understanding of the major technical topics due to their hands-on project experience and distinguish from the traditional instruction method. Since an engineering project usually involves more technical issues than those covered in a traditional engineering analysis course, the teaching approach presented in this paper provides a broad, flexible contextualized alternative to cover technical competence that is different from traditional engineering programs which are made up of structured sequences of lecture-based and laboratory courses.

I. Introduction

Project-based learning (PBL), or project-centered learning (PCL) to distinguish it from the pedagogy of problem-based learning[1], was first adopted by Aalborg University in Denmark[2]. In a PBL course, students are given project assignments and they work in teams to define the problems and determine what they need to know to finish the assignments. It is one version of the inductive learning approach[3] in which students are taught and do self-study of materials after the need for them has been identified through a project's context. Students are highly engaged, active learners and the problems they face are often open-ended. Instead of "expert", as in a lectured-based course, the role of instructors in a PBL course could be more adequately described as "advisor" or "mentor" of the project teams.

In the United States, PBL is often used in senior capstone and freshman cornerstone design courses[4,5]. In addition to meeting the design and problem solving outcomes of ABET Criterion 3[6], PBL also enhances the compliance of other "process skills"[7] requirements of ABET such as ability to function on multidisciplinary teams (3.d), understanding of professional and ethical responsibility (3.f) and ability to communicate effectively (3.g). A detailed discussion on using PBL to teach engineering design is presented in Dym, et al.[8]. This pedagogy has also been adopted by educators in other countries[9].

In most engineering programs, students take courses in their sophomore and junior years that concentrate mainly on engineering analysis. PBL, if used, is usually embedded in various courses that focus on specific technical areas[10-13] to facilitate the learning process. Compared with stand-alone project courses, such embedded PBL approach usually faces more restrictions on its open-ended nature, project selection and technical topics covered. However, students can move quickly into the implementation of a solution.

As explained in the next section, the engineering program at Arizona State University's Polytechnic campus has a sequence of 8 stand-alone project courses through all four undergraduate years. In the junior concentration projects, the required engineering analysis includes technical topics that usually are covered by several lecture-based courses in traditional engineering programs. An embedded module is used to provide students with proper technical background at the beginning of the junior project course. Such flexible structure makes the necessary technical resources for project implementation available to the students without tying such stand-alone project courses to a particular body of technical knowledge.

It is well recognized that most engineering programs are rather similar and structured into sequences of lecture-based courses that are constrained and resistant to any major change[14]. The project-based approach presented in this paper for teaching engineering analysis offers a flexible alternative that breaks the existing barriers among various sequences of engineering analysis courses and contextualize them with a project's assignments.

II. Multidisciplinary engineering program

The engineering program at Arizona State University's Polytechnic campus is a multidisciplinary undergraduate program with its inaugural freshman class started in the fall semester of 2004. It received accreditation under the ABET general engineering criteria in 2010. Its curricular structure, as outlined in Figure1, has an engineering foundation in the first 2 years and primary and secondary focus areas in the third and fourth years. There is a stand-alone project course in every semester. These projects provide hand-on experience that could not be replaced by computer simulations[15]. The primary focus area includes 20 credit hours of focused content, including two junior project courses, and is therefore a larger portion of a student's program of study than the secondary focus area. Currently, there are four primary focus areas in the engineering program i.e. civil infrastructure, electrical systems, mechanical systems and robotics. A student can choose any academic area, from inside or outside of engineering, within Arizona State University as his/her secondary focus area. For example, a student can select Spanish as his/her secondary concentration area and still receive an ABET-accredited engineering degree. On the other hand, a student can use all secondary concentration and elective hours in the same area as his /her primary focus and end up with a program of study similar to those in disciplinary engineering programs. It is believed that such curriculum structure supports the program's brand value of engaged learning, agility and focus on the individual.

In the freshman year, two stand-alone project courses (Introduction to Engineering Design I & II or EGR 101 and 102) emphasizes creativity, problem definition and encourage students to think out of the box to produce a broad range of potential solutions. Since many students have only modest skills in mathematics and sciences, engineering analysis is not a top priority in these two freshman project courses.

In the sophomore year, engineering analysis is covered through a set of engineering fundamental modules, each of them counts for one credit hour. These modules cover traditional topics, such as statics, dynamics, engineering economics, manufacturing, etc., that usually are covered by three or four credit hours lecture-based courses in traditional engineering programs. As demonstrated later in this paper, the lack in depth associated with such modular approach is compensated by the technical contents of the stand-alone project courses plus the four three credit hour courses reserved for each primary focus area, see Figure 1.

In particular, each of the four project courses in sophomore and junior years has an embedded module. These embedded modules are used to cover technical materials necessary for the projects while not available in the fundamental modules. Since most projects involve more than one technical issue, each embedded module usually needs to cover multiple technical topics associated with different engineering analysis courses in more traditional engineering programs. A project can serve as an integrating experience and contextualize those technical topics involved in its execution.

The senior capstone projects come from external sponsors who provide, in addition to real world problems, expertise and financial support. Students from different primary concentration areas within the engineering program described above plus students from other programs at Arizona State University's Polytechnic campus work together as a multidisciplinary team for each project. These capstone projects usually are spread out over both semesters of the senior year.

FRESHMAN (2008/2009)

Revised 1/6/09

1st Semester	Intro to Engineering Design I EGR 101 (3)	Mathematics of Change I APM 265 (3)	First-Year Composition ENG 101 (3)	General Chemistry I (or Science Elective) CHM 113 (4)	The ASU Experience ASU 101 (1)	= 14 CH
2nd Semester	Intro to Engineering Design II Module EGR 102 (4)	Mathematics of Change II APM 266 (3)	First-Year Composition ENG 102 (3)	University Physics I: Mechanics PHY 121 (3)	Critical Inquiry in Engineering I EGR 104 (3)	= 16 CH

SOPHOMORE (2009/2010)

1st Semester	Fall Multi-disciplinary Project EGR 201 (3) Module (1)	Engineering Fundamentals 4 Modules (4)	Engineering Statistics EGR 280 (3)	Mathematics of Change III APM 267 (3)	Unrestricted Elective (2)	= 16 CH
2nd Semester	Spring Multi-disciplinary Project EGR 202 (3) Module (1)	Engineering Fundamentals 4 Modules (4)	Modern Differential Equations MAT 274 or 275 (3)	General Studies (HU/SB) (3)	History of Engineering HTY 316 (3)	= 17 CH

JUNIOR (2010/2011)

1st Semester	Fall Concentration Project EGR 301 (3) Module (1)	Primary Focus Area (3)	Sci Elective (or Chem 113) BIO 187, CHM 116, GLG 101/3, PHY 131/2 (4)	General Studies (HU/SB) (3)	Secondary Focus Area (3)	= 17 CH
2nd Semester	Spring Concentration Project EGR 302 (3) Module (1)	Primary Focus Area (3)	Linear Algebra MAT 343 (3)	General Studies (HU/SB) (3)	Secondary Focus Area (3)	= 16 CH

SENIOR (2011/2012)

1st Semester	Capstone Project I EGR 401 (4)	Primary Focus Area (3)	Primary Focus Math or Science (3)	Unrestricted Elective (3)	Secondary Focus Area (upper div) (3)	= 16 CH
2nd Semester	Capstone Project II EGR 402 (4)	Primary Focus Area (3)	General Studies (upper div) (HU/SB) (3)	Unrestricted Elective (upper div) (3)	Secondary Focus Area (upper div) (3)	= 16 CH

Figure 1. Curriculum Diagram

III. General instruction and evaluation approach

This paper presents our different approach, an assessment of its effectiveness and overall experience in covering engineering analysis in a junior-level project course; EGR 302/394 (2010 Spring Concentration Projects and its embedded module) for those students who choose mechanical systems as their concentration area. The student enrollment comprised 22 students in the Spring semester of 2010. The prerequisites for the courses included Engineering Mechanics: Statics and Dynamics (EGR 221 and 231) and a concurrent requirement of Engineering Thermo-Fluids (EGR 340). The first two courses are engineering foundation modules, as part of the sophomore year's curriculum while the latter is a three-credit hour course that covers thermodynamics, fluid dynamics and heat transfer. It should be noted that, since these modules are basically one credit hour courses, they only address the basic concepts in those technical areas. For example, EGR 231 just covers the kinetics of particles.

The primary objective of this project course is to improve our students' technical knowledge through their project experience in a manner different than both traditional purely-theoretical approach and the project-based learning approach that predominantly introduces the project at the beginning of the semester and students utilize previous knowledge or acquire the necessary background while they address the details of the project. Our approach delays the introduction of the project while a series of project-related lectures is given in the first few weeks of the semester, very similar to the traditional academic approach, that cover the following topics:

- Kinetics of systems of particles
- Computer simulations
- Rocket Propulsion (including Staging)
- Aerodynamics
- Stability

It is important to note that the students are completely unaware of the nature of the projects during delivery of the specifically-designed lectures. Furthermore, homework problems assigned for these topics are carefully designed so that they relate directly to the rocket project described in the following section. The goal is to give students some chance to practice their analysis skills before they work on the project as well as subsequently apply the background gained to toward the successful design of the project system. This is accomplished by also carefully designing the project which is not too open-ended or overly complicated wherein such that the analysis gained from the lectures can only serve as some overall idealized set of guidelines. Instead, the projects are designed such that basic principles introduced during lectures are not only directly applicable but also essential to the success of the project. Quizzes are also administered after the lectures of these topics to evaluate students' comprehension before they devote their full attention to the project. Since there is no existing concept inventories[16] available for those technical topics listed above, quiz problems are also custom made for this project course. Furthermore, the administration of the tests is carried out in such fashion so as to attempt to distinguish the effectiveness of project-based learning. Specifically, the initial few weeks of the semester proceeded in the traditional academic manner and students' comprehension (via the quizzes) is thus evaluated based on the traditional theoretical approach with no experience through specific application. The tests are then re-administered (without of course the students' knowledge) at the end of the semester after the students have completed the project. The scores are compared in an attempt to distinguish and quantify the effectiveness of concept application. Actual samples of both homework assignments and quizzes are posted online (wiki.asu.edu/egr302/spring2010) for readers of this paper.

IV. Project description: EGR302/394 – Rocket propulsion analysis and design of a vertically-ascending rocket system

The twenty-two students enrolled in the course were distributed in five teams of either four or five members each. The teams participated in a competition to design, build, launch and safely retrieve a solid-propellant powered rocket system that adhered to the following:

Requirements and Constraints

1) As part of its payload, the rocket must include the ALT15K/WD Rev2 altimeter. The altimeter should be operational throughout the flight, recording altitude as a function of time. It should be safely returned and be operational after final impact.
2) Any additional payload should be useful, functional and should also be safely retrieved. Useful means that it should produce interesting/meaningful data during the flight, e.g. a camera that produces pictures of the flight, a thermometer that records ambient temperature as a function of altitude, etc.
3) All payload components should be easily detachable such that they can be independently weighed before the final competition launch.
4) The solid-propellant propulsion system's total impulse can not exceed 30 N-s. It is each team's responsibility to demonstrate that the constraint is met at the day of the final competition launch.
5) The total budget for the complete design, fabrication and operation should not exceed $250.
6) Demonstration of design analysis competence. Each team should develop theoretical models that can predict maximum altitude and total time of flight for its rocket system.

A combination of the above requirements and the following criterion will determine the winning team:

Criterion: Optimal payload at highest altitude

Each team should design and optimize the rocket system in order to deliver the maximum payload possible at the highest altitude possible. This can be assessed by maximizing the following payload-adjusted altitude, η:

$$\eta \equiv h_{\max}\left(\frac{m^*}{m_o}\right) \tag{1}$$

where

h_{max} = maximum altitude your rocket achieves during the competition launch
m^* = useful payload delivered and safely retrieved during competition launch
m_o = initial mass of the rocket system during competition launch

Deliverables

Conceptual Design Concept Report (5%)

Project Design Review (Team Oral Presentations)	(10%)
Project Prototype Evaluation	(10%)
Final Design (Team Oral Presentations)	(15%)
Competition Launch	(30%)
Final Project Report	(30%)

Besides optimization of the system through the adjusted-altitude criterion, technical competence and predictive capability were essential and were highly emphasized throughout the course. Consequently, the results from the competition launch aimed to equally evaluate all the above by collecting and scoring in the manner described below.

Prior to the competition each team declared the predicted time of flight (including descent with open parachute or other decelerating method) and predicted adjusted-altitude based on their analytic and/or numerical models of solid body vertical flight along with measured values of the rocket's initial mass, m_o and payload mass, m*. Subsequently, for each launch during the competition the actual time of flight and the actual adjusted altitude were recorded (with a timer and from altimeter data) and the data was evaluated as follows to produce the winning team:

HIGHEST ATTAINED ADJUSTED ALTITUDE, η	**PREDICTABILITY**
1st Place: P_h=10 units of merit	$P_p=\left[10\left(\sqrt{\xi}+\sqrt{\tau}\right)\right]$
2nd Place: P_h=8 units of merit [if $(\eta_2-\eta_1)/\eta_1>5\%$]	where $\xi=\frac{\eta_{pred}}{\eta}$ if $\eta_{pred}<\eta$, $\xi=\frac{\eta}{\eta_{pred}}$ if $\eta_{pred}>\eta$
3rd Place: P_h=6 units of merit [if $(\eta_3-\eta_2)/\eta_2>5\%$]	
4th Place: P_h=4 units of merit [if $(\eta_4-\eta_3)/\eta_3>5\%$]	$\tau=\frac{t_{flight}^{pred}}{t_{flight}}$ if $t_{flight}^{pred}<t_{flight}$, $\tau=\frac{t_{flight}}{t_{flight}^{pred}}$ if $t_{flight}^{pred}>t_{flight}$
5th Place: P_h=2 units of merit [if $(\eta_5-\eta_4)/\eta_4>5\%$]	

Table 1. Formulas for calculating the scores of project teams' rocket designs.

where the subscript/superscript "pred" indicates the team's predicted value of adjusted altitude, η, and total rocket time of flight (including descent), t_{flight}. The evaluation scores were designed to give 2/3 of the total 30 maximum points to the predictive capability of each team's rocket behavior which was predominantly a reflection of the accuracy and rigor of the analytic and/or numerical models emerging from the engineering analysis background that was introduced in the early stages of the semester. In this manner, the students realized that trial-and-error experimentation prior to the launch was not going to be as useful in winning the competition; rather the direct application of the theoretical background with some necessary empirical data was the essential proficiency for success.

IVa. Engineering analysis background

The primary concentration of the engineering analysis introduced by the pre-project lectures focused on several solutions of conservation of momentum (Newton's 2nd Law) of increasing complexity for one-dimensional (1-D) flight:

$$\mathrm{F - mg - D = m\frac{dv}{dt}} \qquad (2)$$

where F=thrust, m=rocket mass, D=aerodynamic drag, v=velocity and g=gravitational acceleration, all variables under no assumptions are functions of time, t. The law can then be combined with the kinematic relation for altitude h, dh/dt=v. The students analyzed and evaluated 1-D flight for three different phases; powered phase, coast phase (F=0 and m=constant) and descent (F=0, m=constant, but different drag coefficient due to decelerating device deployment, e.g. parachute). Emphasis was given in producing closed-form analytic solutions of the equation by utilizing different possible assumptions and using the solutions to evaluate and extract insights about the system's behavior. Such different scenarios varied from the most simplified conceptual system, i.e. thrust and mass are constant and drag is negligible to the most complicated that included all time variations of variables, staging, and atmospheric (variable air density as a function of altitude) and even possible gravitational variations. The most complicated system was of course addressed with a numerical model, methods of which were also introduced during the lectures. In addition, such sequential set of solutions allowed the students to justify certain assumptions/approximations and decide the desired level of accuracy of their model for predicting flight characteristics during the competition.

To better illustrate the value of such analytic approach to the solution of Newton's 2nd law we present the solution under the following assumptions:

a) Rocket thrust and mass are constant throughout the flight.
b) Flow is incompressible, i.e. the drag coefficient, C_D, defined by the expression for drag, $D=1/2\rho v^2 S C_D$, is constant at an average value. (r=air density, S=rocket's cross-sectional area)
c) Environmental/atmospheric conditions are negligible, thus uniform density and g for 1-D flight.

Since the students were designing a rocket system for an optimum payload delivery at the highest possible altitude, i.e. they were maximizing the adjusted altitude, $\eta \equiv h_{max}\left(\frac{m^*}{m_o}\right)$, we present the solution for the altitude gained as a function of both the rocket engine's burn time, t_b and total rocket mass, m_o. In other words, the mass of the rocket for the system design is a variable consisting of the structural mass, m_s, the propellant mass, m_p (assumed constant in this set of assumptions) and the payload mass, m*, i.e. $m_o=m_s+m_p+m^*$. The solution is presented in the same manner as it was required by the students, that is, based on non-dimensionalization using V_t, the terminal speed, $V_t(m_o)=\sqrt{\frac{2m_o g}{\rho C_D S}}$ and T_W, the thrust-to-weight ratio, $T_W(m_o)=\frac{F}{m_o g}$.

Burnout Speed: $$V_{BO}(t_b,m_o)=V_t\sqrt{T_W-1}\ \tanh\left[\frac{gt_b}{V_t}\sqrt{T_W-1}\right] \qquad (3)$$

Altitude:
$$h_{max}(t_b,m_o)=\frac{V_t^2}{g}\left\{\ln\left[\cosh\left(\frac{gt_b}{V_t}\sqrt{T_W-1}\right)\right]+\ln\left[\frac{1}{\cos\left(\frac{gt_b}{V_t}\operatorname{atan}\left[\frac{V_{BO}}{V_t}\right]\right)}\right]\right\} \quad (4)$$

Such closed-form analytic solution is invaluable to the students' understanding of the physical laws and to the optimization of their rocket system for which they were attempting to deliver the maximum useful payload at the maximum altitude possible. To better illustrate the value of such analysis, the maximum altitude, h_{max} and the adjusted maximum altitude, $\eta \equiv h_{max}\left(\frac{m^*}{m_o}\right)$ are presented in Figure 2 as a function of initial mass (which is assumed constant in this set of assumptions), m_o, for a given burn time of a typical solid rocket engine that meets the total impulse requirement of $I \leq 30$N-s.

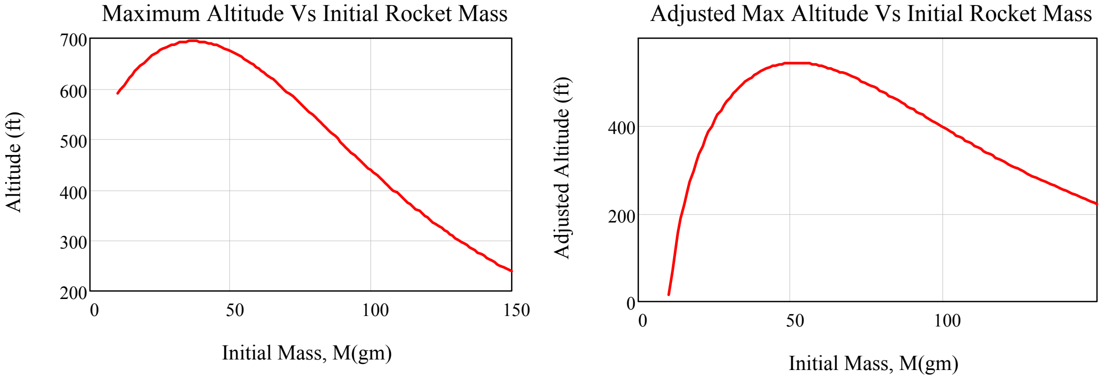

Figure 2. Variation of maximum altitude, h_{max} (eq. 4) [Left] and adjusted maximum altitude, η, [Right] as a function of initial rocket mass, $M=m_o$.

During preliminary conversations with the students attempted an informal survey based on their intuitive estimate regarding designing a light or a heavy rocket in order to reach maximum altitude. All students estimated that they need to design the lightest rocket possible in order to achieve maximum altitude. Their work in producing equation 4 and the left plot of Figure 2 and subsequent analysis showed them that there exists an optimum initial mass for maximum altitude due to the competing effects of gravity and drag, but most importantly served as an example to them of the usefulness and power of analytic solutions regardless of how hard they struggled to produce due to the somewhat more challenging mathematics involved. Furthermore, the students appreciated the insights gained from the variation of the adjusted altitude (Figure 2, right) in their rocket design; the maximum adjusted altitude does not coincide with the maximum altitude and in order to produce a winning design they realized that they need to adjust initial rocket mass based on the optimum value established by the analytic solution. It was also heartening to observe that some students, realizing the value of such closed-form analytic solution, attempted to differentiate the expression for adjusted altitude, unlike numerical or trial-end-error/empirical approaches, to produce an expression for the optimum initial mass as a function of all other design variables.

The lectures and related activities prior to the introduction of the project also addressed a detailed discussion on aerodynamic drag starting from fundamental boundary layer theory to producing relationships that allowed the students to calculate the drag coefficient, C_D without the need for experimentation. Other topics also addressed the fundamentals of rocketry with emphasis on rocket engines, specifically solid rocket propellant engines and associated thrust histograms. The latter discussions were actually quite advanced as to provide the students with the knowledge for predicting the thrust of their chosen engine as a function of time and not rely on manufacturer's specifications. Specifically, the students were introduced to St. Roberts Law which provides a relationship in predicting the burning rate of a composite solid propellant. Homework assignments utilized such law to guide the students in producing closed-form analytic solutions for the thrust histogram of a solid rocket. Most teams used such expressions in their final numerical model in which thrust time variations were taken into account. The lectures also addressed the thermodynamics of nozzle expansion, staging analysis (a very important component which was used by all teams in the design of their rocket system) and for the sake of completeness – even though somewhat irrelevant to the actual project – a series of lectures introduced the different types of propulsion systems including chemical, nuclear, and electric propulsion and some discussion on advanced concepts ranging from solar sails to antimatter propulsion and to more exotic concepts such as the requirements for realization of interstellar missions and close-to or faster-than the speed of light travel.

V. Field test results and assessment of students' learning

The effectiveness of teaching engineering analysis through a hands-on project was assessed in two ways: 1) Since the projects were carefully and specifically designed such that models emerging from engineering analysis would have direct application – not simply providing overall approximate qualitative trends – the models' predictability of the actual system behavior was a legitimate measure of the level of understanding of the physical laws and mathematical tools introduced by the precursor lectures. Hence, part of the quantitative assessment was the predictive success of the students' purely theoretical or semi-empirical models. 2) Since it is virtually impossible to completely eliminate the trial-and-error approach from such hands-on projects, a series of short tests (quizzes) was administered before and after the project. As previously mentioned such approach aimed to distinguish the role of a hands-on project in learning engineering analysis from the traditional predominantly theoretical academic approach.

During the launch competition the five teams, named after historical space missions, competed in optimizing the adjusted altitude and in model predictability. It is essential to reemphasize that the adjusted altitude is NOT the maximum altitude that a rocket can achieve (as usual for such competitions), rather it is a maximum altitude for which the optimum useful payload can be delivered. The results of the competition are outlined in the following table:

Team Name	η(m)	Points, P_h	%difference	Points, P_p	Total Points
Voyager	205	10	NA	18.43	28.43
Gemini	162	8	-17.89	16.95	24.95
Magellan	198	10	-3.45	13.57	23.57
Galileo	72	4	-41.11	17.41	21.41
Cassini	123	6	-24.35	12.95	18.95

Table 2. Results from the five-team competition launch of a vertically-ascending rocket system. The total maximum points accounting for both maximum adjusted altitude, η (see equation (1)) and model predictability is 30. % difference denotes the difference from the next highest adjusted altitude (see Table 1).

The degree of predictability of all teams was quite impressive with the winning team being 92% accurate (18.43/20) in predicting both altitude reached and total time of flight. Such accuracy is notable if we reemphasize that the predominantly theoretical models had to predict three very different flight phases; variable-thrust powered phase, coast phase and decent with the parachute open which entirely changes the drag aerodynamics. Predicting maximum altitude with a given initial mass is relatively straight-forward, producing an adequate model for predicting total time of flight is much more challenging; indeed the results show that the teams performed much better in predicting their rocket's altitude than predicting the total time flight which incorporates free fall with a parachute.

Regardless of the success of the teams' predictions it should be noted that significant tweaking in the models' parameters was possible based on test launches prior to the final competition launch. Indeed, all teams performed such test launches which allowed them to adjust the drag coefficient for all flight phases in such a way such that their models can be more accurate. This could not be avoided which does, to a degree, bias the effectiveness of the purely theoretical engineering analysis due to the semi-empirical nature. In addition, the competition was a team effort within which such effectiveness may be diffused among the members. Hence, the assessment was complemented by a series of individual in-class quizzes that aimed to evaluate how effectual is the hands-on project experience versus the purely theoretical instruction. The weekly quiz problems/questions were designed to be directly relevant to the project, were administered before and after the project (without knowledge of the students), and are available – along with the solutions – at wiki.asu.edu/egr302/spring2010 or by directly contacting the authors. It is important to note that the quizzes were administered the day the associated homework assignment was turned in and the questions/problems were only related to that homework assignment. The students were aware of this, so they only had to concentrate on the topics addressed by that particular assignment. Further, the quizzes were open-book, open-notes but with no access to the particular homework assignment which was submitted right before the short test. The exact same questions/problems were subsequently included in the final examination, (without of course the students' knowledge) which was administered at the end of the semester and after the project was fully completed. The final exam was not open-book, open-notes, but the students were allowed an 8.5"x11" formula sheet. The student performance before and after is outlined in Table 3.

It is readily apparent by comparison of the average scores for each quiz, that there was substantial improvement in the students' understanding of the fundamental principles taught through engineering analysis due to the fact that they had to use such fundamentals for the success of their hands-on project. There was consistent improvement on all tests with the lowest being 21% from Quiz 6 {=(3.24-2.19)/5} and the highest more than 35% from Quiz 1. These scores – which assessed the effect of comprehending and using the fundamentals of engineering analysis on an individual basis – in conjunction with the elevated success of each team to predict their system's behavior based on engineering analysis – strongly supports the effectiveness of an appropriately designed project in teaching engineering analysis to junior engineering students. Emphasis should be once again placed on the nature of the project which by design was not over-complicated such that fundamental physical and mathematical principles emerging from engineering analysis could have direct impact on the project, as opposed to more complicated open-ended projects that fail to demonstrate and prove to the students the value of such engineering analysis.

	QZ1 (10)	Q1FX	QZ2(5)	Q2FX	QZ3 (10)	Q3FX	QZ4 (10)	Q4FX	QZ5(10)	Q5FX	QZ6(5)	Q6FX
1	0.00	8.00	3.00	2.00	10.00	5.00	4.50	8.00	6.00	6.00	0.00	5.00
2	2.00	10.00	3.00	3.00	4.50	5.00	5.00	8.50	8.00	2.00	3.00	0.50
3	8.00	10.00	5.00	5.00	2.00	6.00	9.00	10.00	6.00	10.00	5.00	3.00
4	2.00	8.00	3.00	5.00	5.50	10.00	4.00	6.00	5.00	10.00	0.00	0.00
5	2.00	10.00	3.00	5.00	6.50	10.00	10.00	10.00	7.50	9.50	3.00	5.00
6	8.00	10.00	4.25	5.00	1.00	10.00	4.00	10.00	6.00	10.00	2.00	4.00
7	10.00	10.00	4.00	5.00	0.50	5.00	8.00	10.00	7.00	10.00	3.00	4.00
8	10.00	10.00	5.00	5.00	6.00	10.00	8.50	9.00	5.00	10.00	3.00	5.00
9	2.00	10.00	0.50	5.00	3.00	8.00	6.00	10.00	4.50	9.00	3.00	3.00
10	10.00	8.00	2.50	1.00	3.00	10.00	6.50	10.00	4.00	8.00	3.00	5.00
11	5.00	10.00	2.00	5.00	6.00	10.00	4.00	10.00	5.50	10.00	0.00	5.00
12	8.00	10.00	3.00	3.00	6.00	4.00	6.00	6.00	4.50	3.00	3.00	5.00
13	7.00	10.00	3.00	5.00	6.00	9.50	5.00	10.00	4.50	9.00	2.00	2.00
14	10.00	10.00	2.00	2.00	2.00	5.00	8.00	10.00	5.00	9.00	3.00	5.00
15	10.00	10.00	1.50	5.00	4.00	8.00	3.50	10.00	4.50	8.00	1.00	0.00
16	6.00	5.00	3.00	5.00	2.00	5.00	8.00	5.50	4.00	6.00	2.00	2.00
17	0.00	10.00	4.00	5.00	6.00	8.00	7.00	8.00	4.50	8.00	3.00	2.00
18	6.00	10.00	5.00	5.00	5.00	5.00	7.00	3.50	4.00	8.00	3.00	3.50
19	0.00	10.00	1.50	5.00	1.00	10.00	3.50	10.00	0.00	10.00	0.00	5.00
20	8.00	8.00	3.00	5.00	7.00	10.00	6.00	4.00	4.00	9.00	3.00	3.00
21	8.00	9.00	0.50	5.00	5.50	3.00	4.00	6.00	4.00	2.00	1.00	1.00
Averages	**5.81**	**9.33**	**2.94**	**4.33**	**4.40**	**7.45**	**6.07**	**8.31**	**4.93**	**7.93**	**2.19**	**3.24**

Table 3. Test Performance from 21 students in EGR302/394. Columns headed by QZ*(*) denote scores before the project with (*) being the maximum points available, columns headed by Q*FX denote scores after the project, administered during the final exam. The bottom row denotes the average score from each column and is paired for each quiz for the relevant comparison.

VI. Conclusion

The study evaluated the feasibility and effectiveness of a different approach to enhance students' competence in several technical areas during a junior level stand-alone project course. Specifically, the uniqueness of the approach involved precursor lectures, in the traditional academic manner, that introduced relevant technical topics prior to the introduction of the project details. Tests were administered during this precursor period and evaluated the students' comprehension of the technical topics without any application exposure, i.e. purely theoretical, traditional manner. The project, subsequently introduced, was carefully designed such that the engineering analysis topics covered prior to their introduction had direct and meaningful application to the project and they were essential in the success of the project which involved a competition amongst the student teams. In this manner, the effectiveness of direct application of technical topics via a hands-on project could be distinguished and independently evaluated from the traditional, mainly theoretical academic instruction. Such distinction was made possible by re-administering the test after the project was complete, without the students' knowledge for one-to-one comparison to the pre-project performance.

Assessment of the effectiveness of such approach was also possible by designing the projects' competition such that predictive capability using the engineering analysis models based on physical laws was essential in the students' success. Indeed, the students' performance in predicting the behavior of their systems was impressive, reaching as high as 92% accuracy in predicting the altitude reached and the total time of flight of a model rocket that they designed. Furthermore, comparison of the pre- and post-test scores showed consistent improvements in all technical areas tested reaching as high as 35%.

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