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Using a Stand-Alone Junior Project Course as a Platform for Teaching Engineering Analysis of Mechanical Systems*

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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' competences 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. Is it possible to use an independent project course to effectively teach engineering analysis and the challenging technical concepts that it involves? This paper presents the results of a study on the effectiveness of teaching engineering analysis of mechanical systems through a stand-alone project course. Our approach introduces the technical topics in the traditional academic manner prior to introducing the students to the project details. The model-rocket project was carefully and very specifically designed such that the technical topics of the pre-project lectures had direct and meaningful applications and were essential to its success. Based on this approach, the results demonstrated that the predictive success of the students' theoretical models of their rocket systems' behavior reached as high as 92%. Identical pre- and post-project tests showed consistent performance improvement reaching as high as 35%. This data suggests that it is possible to effectively utilize the PBL approach to teach the challenging technical subjects associated with engineering analysis. The main ingredient is the specific design of the projects such that the predictive capability of theoretical models is essential in evaluating students' project success.

Keywords: Project-Based Learning; engineering analysis; modeling

1. 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 the ability to function on multidisciplinary teams (3.d), an understanding of professional and ethical responsibility (3.f) and the ability to communicate effectively (3.g). A detailed discussion on using PBL to teach engineering design is presented in [8]. This pedagogy has also been adopted by educators in other countries [9].

In most engineering programs, students take courses during 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 such as power electronics [10–11], nuclear fuel cycle [12] and thermal sciences [13–14] to facilitate the learning process. Compared with stand-alone project courses, the project played only a minor role (less than 15% of the course grade, see [14]) in such embedded PBL approach. Also, project selection is restricted because, being part of a specific technical course, it must cover the corresponding technical topics [10–14]. Since most real-world engineering projects involve more technical issues than those covered in a single engineering course, it is desirable to design a PBL experience that integrates, contextualizes and enhances the technical knowledge associated with multiple courses in traditional engineering curricula.

The engineering program at Arizona State University's Polytechnic campus is a multidisciplinary undergraduate program with its inaugural freshman class having started in the fall semester of 2005 [15]. It received accreditation under the ABET general engineering criteria in 2010. As outlined in Fig. 1, its curricular structure has an engineering foundation in the first two years and

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primary and secondary focus areas in the third and fourth years. There is a stand-alone project course in every semester. These projects provide hands-on experience that could not be replaced by computer simulations [16]. The primary focus area includes twenty 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. mechanical systems, civil infrastructure, electrical 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 focus area and still receive an ABET-accredited engineering degree. On the other hand, a student can use all secondary focus 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.

In the freshman year, two stand-alone project courses (Introduction to Engineering Design I & II or EGR 101 and 102) emphasize 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., which are usually 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 a 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 Fig. 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 that are necessary for the

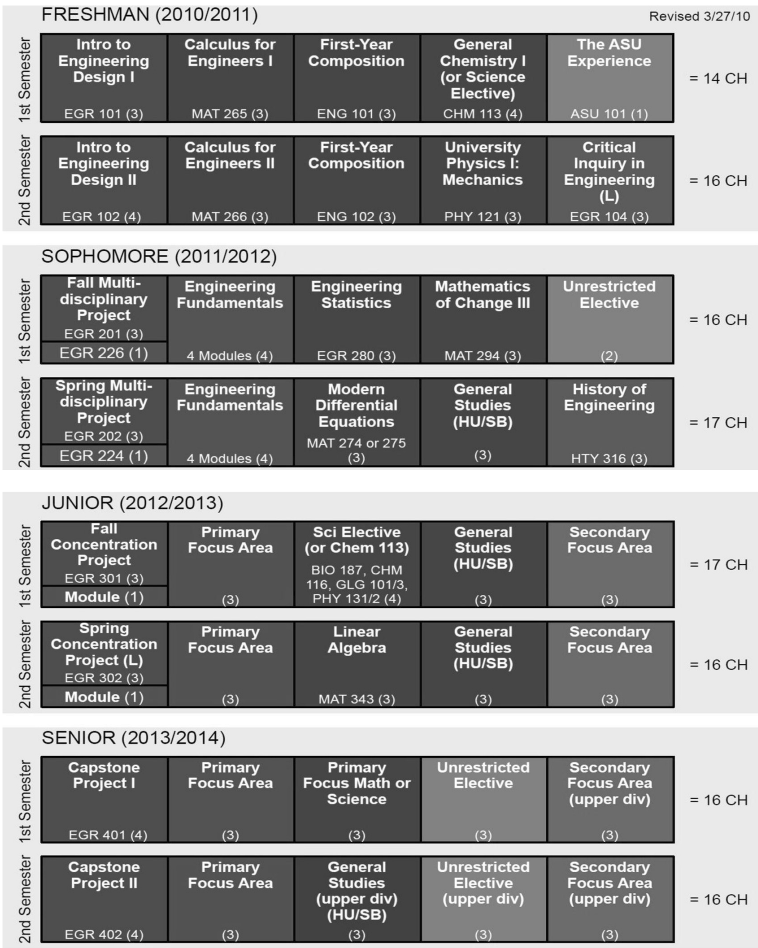

Fig. 1. Curriculum diagram of ASU-Poly's Engineering program.

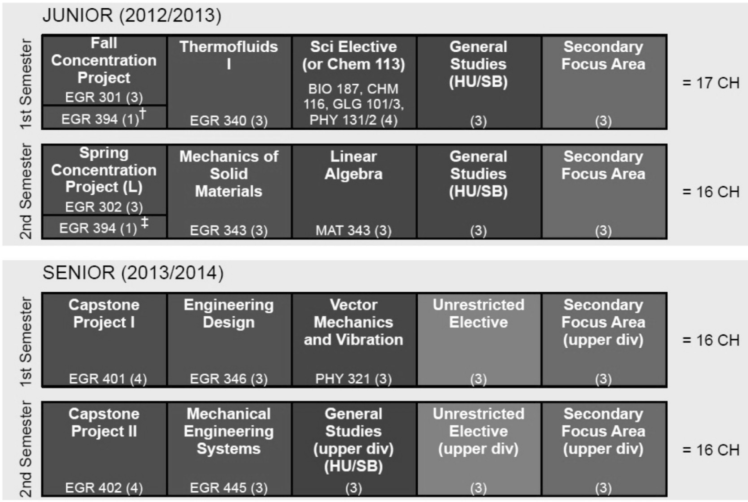

Fig. 2. Curriculum diagram for the mechanical systems focus area.

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. 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. A project can serve as an integrating experience and contextualize those technical topics involved in its execution. Since this paper concentrates on the mechanical systems focus area, its curricular structure for the juniors–senior years is presented in Fig. 2.

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 [17]. The project-based approach presented in this paper for teaching engineering analysis of mechanical systems offers a flexible alternative that breaks the existing barriers among various sequences of engineering analysis courses and contextualizes them with a project's assignments.

2. Research method and evaluation approach

The primary objective of this study is to improve our students' technical knowledge through their project experience in a manner that is different from both the traditional purely theoretical approach and the project-based learning approach that predominantly introduces the project at the beginning of the semester: 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. For the specific project course discussed in this paper the following topics were addressed:

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

As any person that is knowledgeable in mechanical engineering curricular can tell, these technical topics usually are covered in several different courses in traditional engineering programs.

It is important to note that the students were completely unaware of the nature of the project during delivery of the specifically-designed lectures. Furthermore, homework problems assigned for these topics were carefully designed so that they relate directly to the rocket project described in the following sections. 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 toward the successful design of the project system. This is accomplished by also carefully designing the project not to be 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 project is designed such that basic principles introduced during lectures are not only directly applicable but they are also essential to the success of the project. Quizzes were also administered after the lectures on these topics to evaluate students' comprehension before they devoted their full attention to the project. Since there is no existing concept inventories [18] available for those technical topics listed above, quiz problems were also custom made for this project course. Furthermore, the administration of the tests was carried out in such a fashion 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) was thus evaluated based on the traditional theoretical approach with no experience through specific application. The tests were then re-administered (without of course the students' knowledge) at the end of the semester after the students had completed the project. The scores were compared in an attempt to distinguish and quantify the effectiveness of concept application. Actual samples of both homework assignments and quizzes are available by request from the authors of this paper.

3. Project description

This paper presents our experience in covering engineering analysis in a junior-level project course, EGR 302/394 (2010 Spring Concentration Project and its embedded module), for those students who chose mechanical systems as their primary focus area. The prerequisites for the mechanical systems focus area include Engineering Mechanics: Statics and Dynamics (EGR 221 and 231) with 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 the two modules are basically one credit hour courses, they only address the basic concepts in those technical areas. For example, EGR 231 just covers particle dynamics.

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

3.1 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 this 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.

3.2 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:

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

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 following manner.

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

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

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}.

Prior to the competition launch, 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 were evaluated (Table 1) to produce the winning team.

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.

3.3 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 Second Law) of increasing complexity for 1-D flight:

$$F - mg - D = m(\mathrm{d}v/\mathrm{d}t), \quad (2)$$

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, $\mathrm{d}h/\mathrm{d}t = v$. 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, which 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 Second Law we present the solution under the following assumptions.

1. Rocket thrust and mass are constant throughout the flight.
2. Flow is incompressible, i.e. the drag coefficient, C_D, defined by the expression for drag, $D = \left(\frac{1}{2}\right)\rho v^2 SC_D$, is constant at an average value (ρ = air density, S = rocket's cross-sectional area).
3. Environmental/atmospheric conditions are negligible, thus uniform ρ 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 was required of the students, that is, based on non-dimensionalization using V_t, the terminal speed,

$$V_t(m_o) = \sqrt{\frac{2\ m_o g}{\rho C_D S}}$$

and T_W, the thrust-to-weight ratio, $T_W(m_o) = \frac{F}{m_o g}$

Burnout Speed:

$$V_{BO}(t_b, m_o) = V_t\sqrt{T_W - 1}\ \tanh\left[\frac{g t_b}{V_t}\sqrt{T_W - 1}\right] \quad (3)$$

Altitude:

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

Such a 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, $\eta \equiv h_{max}\,(\frac{m^*}{m_o})$, are presented in Fig. 3 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.

During preliminary conversations with the students an informal survey was attempted based on their intuitive estimate regarding designing a light or a heavy rocket in order to reach maximum altitude. All students estimated that they needed to design the lightest rocket possible in order to achieve maximum altitude. Their work in producing Equation (4) and Fig. 3(b) and subsequent analysis showed them that there exists an optimum initial mass for maximum altitude due to the competing effects of gravity and drag. More importantly, it served as an example of the usefulness and power of analytic solutions, regardless of how hard they struggled to produce them due to the somewhat more challenging mathematics involved. Furthermore, the students appreciated the insights gained from the variation of the adjusted altitude (Fig. 3(b)) 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 have 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 a 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 so 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 a 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 that was used

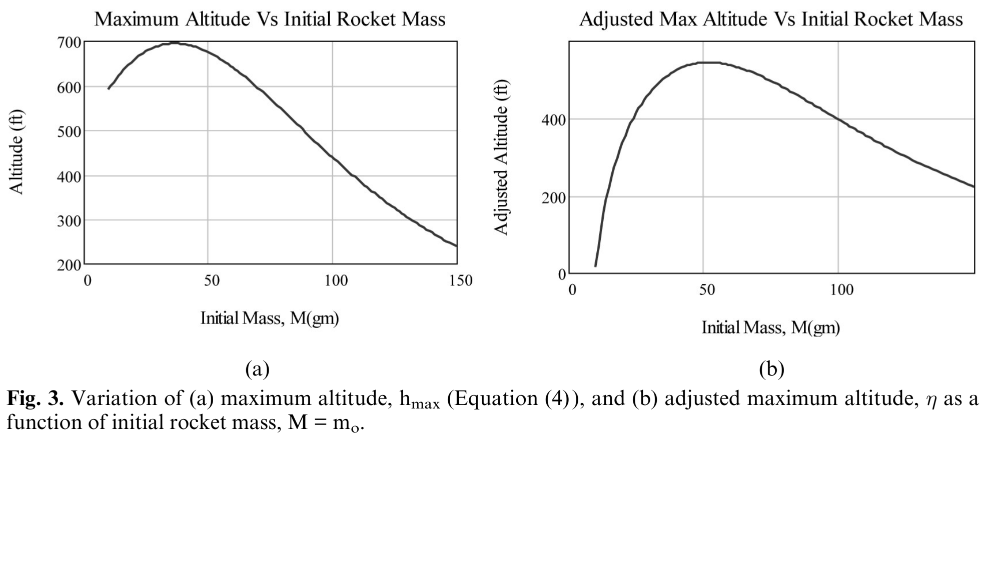

Fig. 3. Variation of (a) maximum altitude, h_{max} (Equation (4)), and (b) adjusted maximum altitude, η as a function of initial rocket mass, $M = m_o$.

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 as well as more exotic concepts, such as the requirements for the realization of interstellar missions and close-to or faster-than the speed of light travel.

4. 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 project was 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 project, a series of short tests (quizzes) was administered before and a comprehensive exam was administered 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 re-emphasize that the adjusted altitude is not the maximum altitude that a rocket can achieve (as is 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 Table 2.

The degree of predictability of all the 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 re-emphasize that the predominantly theoretical models had to predict three very different flight phases; variable-thrust powered phase, coast phase and descent 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 in predicting the total time flight that 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 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—by directly contacting the authors. It is important to note that the quizzes were administered the day the associated homework assignment was submitted 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 parti-

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)

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

cular assignment. Further, the quizzes were open-book, open-notes but with no access to the particular homework assignment that 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″ × 11″ 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 as 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. Since the number of students (21) involved in this study is much lower than other pedagogical studies [16, 19], no statistical evaluation of the significance of these improvements between pre- and post-tests was conducted.

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 support the effectiveness of an appropriately designed project in teaching engineering analysis of mechanical systems to junior engineering students. Emphasis should be once again placed on the nature of the project that, 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.

5. Conclusions

This 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, which introduced relevant technical topics prior to the introduction of the project details. The project—subsequently introduced—was carefully designed such that the engineering analysis topics covered prior to its 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. The effectiveness of such an approach is supported by the students' impressive performance in predicting the behavior of their system, 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%.

Table 3. Test performance from 21 students in EGR302/394. Columns headed QZ*(*) denote scores *before* the project with (*) being the maximum points available, columns headed 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

	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**

It is undeniable that one of the most challenging aspects of an engineering program is accomplishing the technical competence levels desired that are associated with engineering analysis. Although the initial results look encouraging, establishing and quantifying the potential impact of our approach is somewhat premature based on only one course and a project that is, in some sense, academic in nature. However, we are working on collecting further data from designing similar project courses with an objective that seeks to incorporate simpler versions of more complicated, edge-of-research projects that are currently challenging major corporations and research organizations.

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