AC 2008-1376: FOOTBALLS, ROCKETS, AND LEGOS: A HANDS-ON APPROACH TO ENHANCING THE QUALITY OF ENGINEERING DESIGN EDUCATION

Joel Dillon, United States Military Academy

Jose Salinas, United States Military Academy

Footballs, Rockets and LEGOs™: A Hands-on Approach to Enhancing the Quality of Engineering Design Education

Abstract

ME450, a course developed to provide a capstone design experience to non-engineering majors at the United States Military Academy at West Point, has for three years successfully presented the mechanical engineering design process to students enrolled in humanities, social sciences, life science and other non-engineering degree programs. The effectiveness of the course at inspiring this somewhat reluctant student population to get excited about applying engineering principles and problem-solving techniques is primarily due to a syllabus that is structured around three engineering design projects, or EDPs. These projects, which become progressively more complex throughout the semester, require students to take taught theory out of the classroom and apply it to the design of mechanical systems. Observations and data collected over the course of the previous three years, to include direct student feedback and an analysis of embedded learning indicators, indicates that these design projects promote effective learning in direct proportion to the level of effort that students are willing to dedicate toward their completion. Clearly, students who embrace the challenges presented to them and strive to fully understand and design innovative EDP solutions come away with a much richer learning experience than students who limit their involvement to the minimum requirements.

This conclusion, while not unexpected, poses an interesting challenge: how do you structure the course in such a way that it encourages the kind of dedicated involvement that is critical for effective learning to take place? The nature of the projects presented is, of course, an extremely important contributor. The second and third EDPs are carefully designed to be uniquely relevant to student experience and interest and, for the first time, the initial EDP has been assigned as a "self-selected" design project in which the students themselves are required to focus on solving a problem of their own choosing. This novel approach has produced remarkably positive results in terms of student enthusiasm and motivation to innovate, greatly enhancing the overall quality of the introductory design experience, which is targeted at reinforcing the conceptual fundamentals of the engineering design process presented in the classroom.

The second EDP, a water bottle rocket design, introduces the concept of the application of a theoretical model to predict "real-world" results, while the third and final EDP, a LEGO™ Mindstorms™ vehicle design, presents a complex technical problem design to challenge students' analytical and creative abilities. The most significant obstacle to learning in both of these technical projects is an observed tendency of students to over-simplify or fail to fully grasp the full extent of the problems presented. When this happens, students invariably develop perceptions that the engineering design process is, at best, unnecessary and, at worst, a hindrance to effective problem solving. To counteract this dynamic, the most recent evolution of ME450 has incorporated four new laboratory exercises intended to challenge students to delve into specific aspects of the assigned EDPs and, by doing so, derive a better appreciation of the complexity of the technical problems involved. This heightened understanding has the effect of promoting a more universal enthusiasm for the application of the engineering design process, as

students are forced to realize that successful innovation is not possible without a coherent, methodical approach to problem solving.

This paper will provide a qualitative assessment of the effectiveness of ME450's refined approach to teaching mechanical engineering design. The impact of the introduction of a self-selected design project and the new lab exercises on student learning will be quantified by analysis of embedded indicators and course-end student feedback. The results of this assessment should be useful to any program which intends to enhance the quality of its engineering design curriculum, particularly in courses offered to non-engineering majors.

Introduction

Students at the United States Military Academy (USMA) must demonstrate proficiency in six key domains in order to graduate:

- Engineering and Technology
- Math and Science
- Information Technology
- History
- Culture
- Human Behavior

The goal of exposing students to each of these areas is to create well-rounded graduates who appreciate not only history, culture, and the social sciences, but also math and engineering as well. Unfortunately, achieving this goal is certainly not without its challenges. While it is a common practice at many Universities to require engineering students to take courses in the liberal arts, the opposite is often not the situation. At USMA, however, all graduates receive a Bachelor of Science degree regardless of their academic major. With this in mind, students who choose to major in the liberal arts are required to take, at a minimum, a three-course engineering 'core' sequence from one of the Academy's eight engineering programs in order to graduate. Table 1 shows the three-course core sequence for the Mechanical Engineering Department:

Table 1. Mechanical Engineering Three-Course Core Sequence

Course	Content
Statics and Materials	Static Analysis of Rigid Structures, Stress, Strain, Bending, Torsion
Introduction to Thermal Systems	Fundamentals of Fluid Mechanics, Thermodynamics, and Heat Transfer
Mechanical Engineering Design	Design Process and Techniques, Aerodynamic Stability, Torque, Power, and Gear Trains

The purpose of this engineering sequence is to achieve the institution's Engineering and Technology goals shown below. These twelve goals incorporate all six elements of Benjamin Bloom's Taxonomy of Educational Objectives, and while they are geared towards West Point, they are certainly not unique; most engineering programs at other Universities have similar goals. However, applying these goals to non-engineering majors, as is the case at USMA, is at the very least, an ambitious proposition.

Table 2. United States Military Academy Engineering and Technology Goals

Upon successful completion of the engineering sequence, students should be able to:

1. Identify a need that can be fulfilled via an engineered solution.
2. Define a complex technological problem, accounting for its political, social, and economic dimensions.
3. Determine what information is required to solve a technological problem; acquire that information from appropriate sources; and, when available information is imperfect or incomplete, formulate reasonable assumptions.
4. Apply the engineering design process and use appropriate technology to develop solutions that are both effective and adaptable.
5. Demonstrate creativity in the formulation of alternative solutions to a technological problem.
6. Apply mathematics, basic science, and engineering science to model and analyze a physical system or process; and apply the results of that analysis to the solution of a technological problem.
7. Work effectively as a member of a team to solve a technological problem.
8. Plan the implementation of an engineering solution.
9. Communicate an engineered solution to both technical and non-technical audiences.
10. Assess the effectiveness of an engineered solution. Demonstrate basic-level technical proficiency in an engineering discipline.
11. Demonstrate basic level technical proficiency in an engineering discipline.
12. Learn new concepts in engineering and new technologies without the aid of formal instruction.

Many of the liberal arts majors at West Point readily admit that they would not voluntarily take any technical classes if it was not necessary to do so. Therefore, requiring them to enroll in fairly rigorous engineering courses in order to graduate certainly does not make for a classroom full of highly motivated students. To further complicate matters, the enrollment is limited for each engineering program's core sequence; so many non-engineering majors do not receive their first program of choice. Combined with the fact that the Mechanical Engineering sequence is often viewed as one of the most academically difficult at USMA, many of the students taking this sequence did not place it as their first, second, or even third choice. These details add up to a very challenging teaching environment for the instructors of Mechanical Engineering core sequence courses at West Point.

Given the difficulty of the situation, the USMA Mechanical Engineering sequence has done an excellent job of overcoming the initial lack of student motivation in its third and final course of the sequence, ME450. The effectiveness of this capstone course at inspiring a somewhat reluctant student population to get excited about applying engineering principles and problem-solving techniques is primarily due to a syllabus that is structured around three engineering design projects, or EDPs.

Engineering Design Projects (EDPs)

ME450 teaches mechanical engineering design by incorporating unique teaching styles and course material to include three Engineering Design Problems (EDPs) that are geared towards generating student interest and excitement. These projects, which become progressively more complex throughout the semester, require students to take theory out of the classroom and apply it to the design of real mechanical systems.

Historically, the first of these EDPs was the least enjoyed by students: an individually-assigned, pre-designated project related to thermodynamics and fluid mechanics. The reasoning behind using this problem was the fact that all of the students had recently taken a thermo-fluids course and could focus on learning the design process without needing to simultaneously learn new mathematical or theoretical concepts. For the most recent semester, however, this initial EDP was assigned as a "self-selected" design project in which the students themselves were required to focus on solving a problem of their own choosing. This novel approach produced remarkably positive results in terms of student enthusiasm and motivation to innovate, greatly enhancing the overall quality of the introductory design experience.


Figure 1: EDP2 Water Bottle Rockets

The second EDP, a water bottle rocket design, introduces the concept of the application of a theoretical model to predict "real-world" results. In this EDP, students work in teams to design, build, and test a water rocket. They are taught aerodynamic stability concepts during the process in order to evaluate their designs. The EDP culminates with a competition between design teams that generates excitement by igniting a competitive spirit between teams.

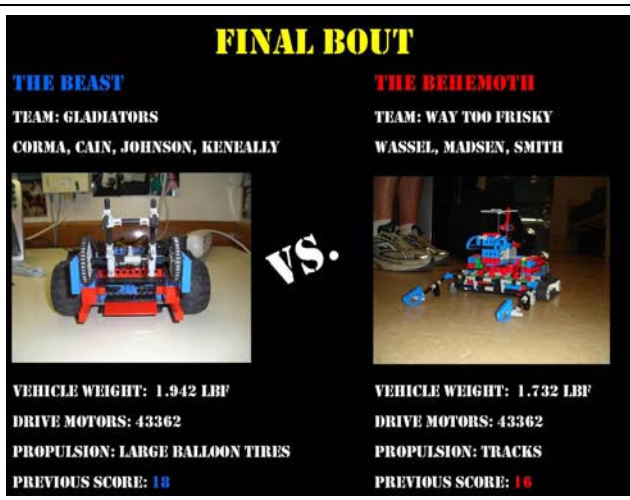


Figure 2: EDP3 LEGO™ Vehicles

The third and final EDP is also the most complex. Student design teams must design and build a LEGO™ vehicle and then compete with other teams in an 'arena' where they score points by depositing ping pong and golf balls in various scoring locations. During the design process, students are taught the concepts of torque and power, and learn to analyze and construct gear trains for their vehicles. This EDP presents a complex technical problem designed to challenge students' analytical and creative abilities.

The Problem

As the capstone course for the Mechanical Engineering sequence for non-majors, ME450 rightly has the goal of achieving the higher-level objectives of Bloom's Taxonomy: Application, Analysis, Synthesis and Evaluation.[1] Consequently, the course objectives and supporting lesson objectives for this course are also geared towards accomplishing these upper-level educational objectives. In order to measure the effectiveness of the course at achieving these educational objectives, student performance in events with direct correlation to the course objectives is assessed. These events serve as embedded indicators that allow course evaluators to develop a very accurate picture of how well students are progressing through Bloom's Taxonomy of Educational Objectives. Positive course-wide performance in events tied directly to objectives pertaining to the higher-level skills of analysis, synthesis and evaluation are viewed as an indicator that the course is, in fact, helping students to effectively develop these critical cognitive abilities.

At the end of the first semester of the 2007 Academic Year, an analysis of student performance in these embedded indicators, along with the results of course-end student surveys and instructor observations, began to raise a concern that some of the 95 students enrolled in the course were failing to fully achieve USMA Engineering and Technology Goals 6 and 12 (see Table 2) and were consequently not reaching the higher-level objectives of Bloom's Taxonomy. This was due primarily to the fact that these students were not completely grasping the physical principles governing the success or failure of their engineering design projects. This failure to fully understand physical principles was attributed to a tendency by some students to over-simplify or fail to completely grasp the full extent of the problems presented. When this happened, students invariably developed perceptions that the engineering design process was, at best, unnecessary and, at worst, a hindrance to effective problem solving.

The following comments, excerpted from course-end reflective student essays illustrate this particular area of concern:

"The modeling and analysis was so nebulous a concept that I grew to hate it."

"During this project, we were required to apply principles and concepts without fully understanding them."

"I only began to learn about how gears affected speed and torque when I was able to build a drivetrain with my own hands and observe how it worked."

"This course failed to capture my imagination, and never really challenged me. I failed to learn anything that I did not know already." (This comment was written by a student whose final design performed very poorly in the course-end competition)

"I feel like I have never been able to understand the theory and methodology of our designs very well. If we could go a little more in depth when the problem is presented in class, I think that I would be better off."

The Approach

To counteract the dynamic of students failing to grasp critical concepts, the most recent evolution of ME450 incorporated four new laboratory exercises intended to challenge 60 new students to delve into specific aspects of the assigned EDPs and, by doing so, derive a better appreciation of the complexity of the technical problems involved.
In order to facilitate student learning, a crawl-walk-run methodology was employed for the four new laboratories. This approach was based on United States Army Training Doctrine.[2, 3] While this may at first seem to be an unlikely source of inspiration for teaching in an academic environment, the Army has, in fact, been focused on effectively teaching complex subject matter to college-aged students for literally hundreds of years and therefore has a wealth of institutional knowledge and experience in this area. This institutional teaching knowledge, while certainly valuable, is often overlooked in purely academic environments. Although using this novel approach clearly works well at West Point where future Army Officers are being trained, it almost certainly has applicability at other universities as well.

Following the crawl-walk-run methodology, instructors worked from very simple to progressively more complex concepts with the students. Using this model, the first new laboratory was introduced for EDP 2 in order to help students understand basic aerodynamic stability. Entitled the "Football Lab," it was conducted outside with three different types of small footballs and a water balloon slingshot. Students prepared predictions for the trajectories of the footballs using a computer spreadsheet program that was built specifically for the laboratory. Following the crawl-walk-run model, instructors initially limited the complexity of what could have been seen by the students as overwhelmingly complex aerodynamic equations. By setting up the spreadsheet to use the spring potential of the slingshot and the laws of projectile motion, the instructors initially left only the coefficient of drag as the most significant indeterminate variable for students to determine. The students launched their footballs (a fun exercise in itself) and then compared the actual flight performance of the footballs to what they had predicted prior to the laboratory. They then used an iterative method to determine a more accurate coefficient of drag for each ball. Along with the computer spreadsheet, students were given laboratory handouts that followed the crawl-walk-run concept as well. The initial questions were very simple, scripted "fill-in-the-blank" problems that progressively worked up to more open-ended questions at the end, requiring students to evaluate the reliability of the theoretical model and explain discrepancies between predicted and actual performance. A copy of the lab handout appears as Appendix A.

Figure 3: Football Lab

Figure 4: Students using rocket design spreadsheet to optimize performance during rocket competition

The positive benefit of using this methodology was that it prepared students to incorporate energy analysis and conservation of momentum in determining the thrust calculation for their water bottle rockets. While fun for the students, the Football Lab had the effect of drawing them in to the theory behind their water bottle rockets and helped them better understand the complexity of the problem. By starting simple and working up to progressively more complex concepts, students were less likely to decide that the material was too difficult and stop paying attention. The lessons that they learned in the football lab about coefficient of drag estimation were then directly applied to the rocket design, along with a newly developed understanding of the effect created by the relationship between center of gravity and center of pressure. The final water bottle rocket competition then served as the 'run' portion of the crawl, walk, run methodology.

Following the success of the Football Lab, three additional laboratories were introduced for EDP 3. The goal of this series of laboratories was once again to introduce the students slowly to the theory behind their design and then to progress towards more complex concepts. The first of these laboratories dealt with gear trains. This 'Gear Lab' focused solely on teaching students gear train construction principles and techniques. The student design teams built and tested static gear trains to lift a set amount of weight with a pulley. The students' goal was to lift the weight a set distance as quickly as possible, and teams that performed well were rewarded with bonus points. The simple gear trains built by the students used only one motor, but required them to determine torque and angular velocity ratios as well as gear box efficiency for their prototypes. Students were also required to use torque and power curves for their motor to determine how to obtain the maximum power output given a constant load. Similar to the Football Lab, students were also given a laboratory handout that followed the crawl-walk-run methodology. The questions progressed from simple to open-ended evaluations of their designs and the theory behind them.

By starting with only the gear train, students did not have to worry yet about steering, traction, or multiple motors – those would come later in the EDP. As a result of the Gear Lab, students learned important gear train concepts such as avoiding cantilevers, using short shafts, and ensuring that gears mesh properly to prevent friction losses. They also had the opportunity to see that torque and power curves are more than simply lines on a piece of paper, but instead tools that, when used correctly, can genuinely increase the output performance of a gear train.

The second laboratory for EDP 3 built upon lessons learned from the Gear Lab as well as new concepts taught in class. The 'Traction Lab' focused on teaching students the concept of traction by conducting a simple tractor pull with LEGO™ vehicles. While still only one motor was used for the student prototypes, instructors added another degree of freedom by introducing a new motor with different torque and angular velocity characteristics. This allowed students to have a choice between two motors and forced them to begin applying the design process for the lab. Students examined the interaction between tires and the ground and were allowed to experiment with and observe the relative effectiveness of various tire compounds and types. Additionally, the laboratory showed the effect of drive axle weight and normal force on traction – a concept that they had seen on the chalkboard, now playing out in reality. Some students started to fully grasp the concept and even take it a step further when they identified that by allowing the front wheels to lift off of the ground, all of the vehicle weight is transferred to the drive axle on a rear-wheel drive vehicle, allowing it to operate with the maximum possible traction. Again, students were provided with a lab handout that followed the same crawl-walk-run methodology.

The final new laboratory for EDP 3 was entitled the 'Speed Lab' and exposed students to the general principles of vehicle handling and stability. For this lab, students now had the opportunity to use two motors of their choosing and were also required to include steering in their design. This lab continued to build on the first two by requiring students to design and construct a gear train and to select appropriate tires or tracks. Students were encouraged to build prototypes based on concept vehicles that they had started to develop for their final competition vehicle. While the lab itself did not require students to conduct new mathematical calculations, it did involve a discussion of the general geometry and principles, such as track width and wheel base, that affect a vehicle's ability to maneuver. Additionally, the laboratory allowed students to see the effects of rolling resistance, a concept that had been introduced in class, but was still purely theoretical to the students until this point. Similar to the Football Lab, a new analytical spreadsheet was introduced to the students which allowed them to approximate vehicle speed prior to actually building their vehicles. Like the Gear Lab and the Traction Lab, students competed for bonus points, this time by driving their vehicles around a serpentine race course for time.

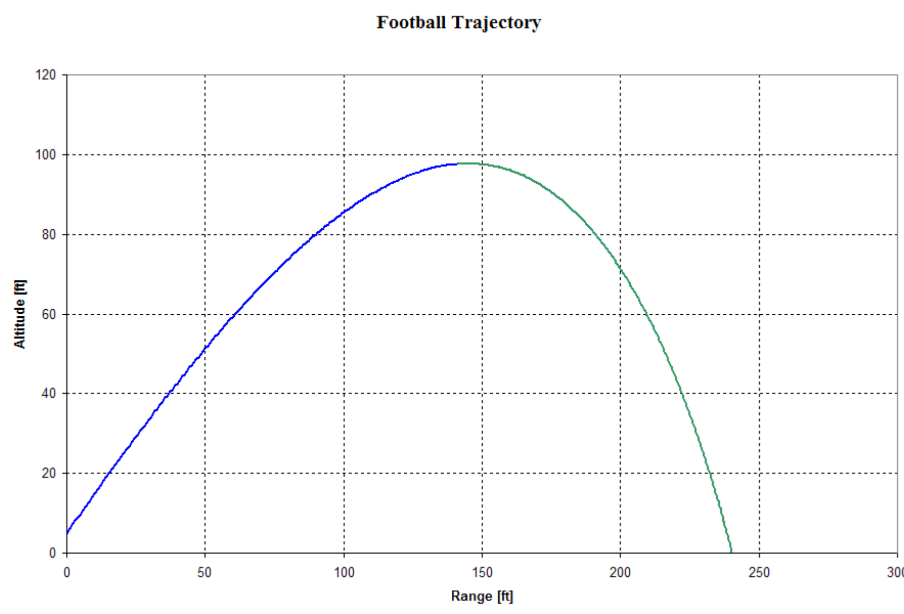
The Speed Lab gave students the opportunity to familiarize with controllers used in the competition, to get a bit of practice driving vehicles remotely, and to start getting excited about the final event. Like the other two EDP 3 labs, the Speed Lab generated a competitive spirit as students competed for bonus points and bragging rights. Some students were motivated to learn the theory behind the design problem so they could build a better vehicle and beat another team. Competition proved to be a powerful motivator throughout the course.

Like EDP 2, the final competition for EDP 3 served as the 'run' phase of the crawl-walk-run model. Student teams competed with their vehicles in an auditorium on a raised arena in front of their classmates and other audience members. The event was complete with music, an overhead camera and an MC and proved to be a huge success with both the cadets and other faculty members. The inclusion of laboratory exercises clearly had had a beneficial effect on student learning, specifically with relation to an overall increase in the effectiveness of student designs when compared to previous years, as well as enhanced student ability to recognize the impact of theory on design and focus innovation efforts on overcoming technical problems.

The Results

The introduction of new laboratory exercises resulted in the development and introduction of new theoretical tools for use in the course. The goal of these tools, like the labs they supported, was to help students better visualize the relationship between mathematical concepts and prototype performance. For EDP 2, a spreadsheet-based program was constructed that allowed students to immediately see both a graphical two-dimensional trajectory plot and numerical results of a projectile's predicted flight path after entering basic information about the projectile in question and the ambient environmental conditions. Two versions of this program were introduced during EDP 2, the first to be used with the Football Laboratory and the second to predict water rocket flight performance. Students were not given access to this flight predictor program until their design groups clearly demonstrated proficiency in the basic underlying equations used in the program by correctly solving example problems based on the same theory.

Figure 5. Football Flight Predictor Trajectory Plot



After gaining access to the program, students were required to use the football flight predictor prior to the football laboratory in order to predict range and altitude for each of three footballs. The actual conduct of the laboratory forced them to delve deeper into the program in order to estimate more realistic drag coefficients for each football. By executing the laboratory in this manner, students became familiar with the spreadsheet and its underlying theory prior to the introduction of the second similar, but more complex, program to predict water rocket flight performance. This second program aimed to help the students quickly predict flight characteristics of their rocket designs in order to both evaluate potential concepts during the design process and to help determine proper launch angles, air pressure and water volume for actual prototype testing and the final graded launch.

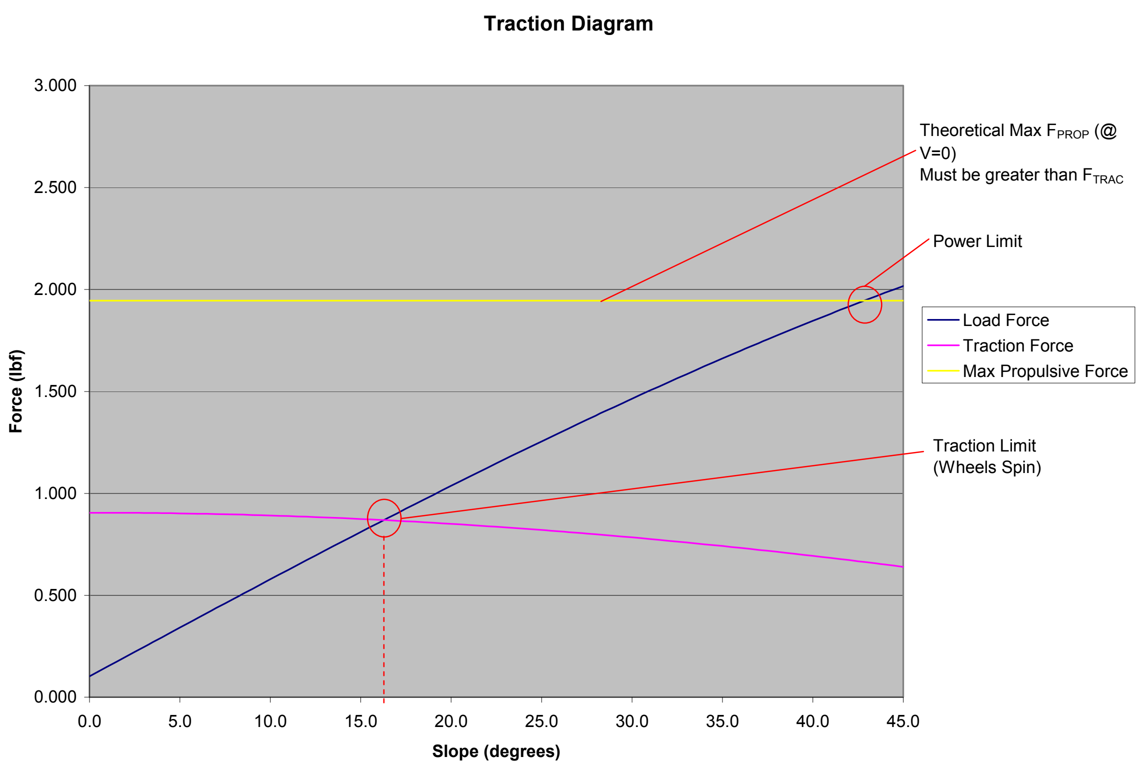
These programs were not without their flaws, however. Many students complained that the second installment of the program failed to provide accurate predictions during the first rocket test launch. This test launch, conducted outside on a breezy day, was not accurately modeled by the program. This could certainly have proven detrimental to learning had the students decided that the program, and hence the theory behind it, was worthless in predicting flight characteristics. In order to prevent this from happening, wind speed was added to the calculations. By having this small change to the spreadsheet and an anemometer to measure wind speed for subsequent launches, students were able to actively update their flight predictions prior to launch. This change made the model much more accurate and encouraged students to bring their laptops to the launches in order to more accurately set proper launch angles, air pressure and water volume for the current wind and temperature conditions.

Figure 6. Excerpt of Improved Rocket Flight Predictor Spreadsheet

	F	G	H	I	J	K	L	M	N	O	P	Q	R
1								Temp	rho_air	rho_h20		d/D	K_L
2	20	C		DO NOT CHANGE				10	999.7	1.246		0.2	0.3
3	998	kg/m^3		User Inputs				15	99.1	1.225		0.3	0.275
4	1.204	kg/m^3		Data at Fuel Burnout				20	998	1.204		0.4	0.25
5	0.1	kg		Data at apex				25	997	1.184		0.5	0.2
6	0.1	kg		Data at landing				30	996	1.164		0.6	0.15
7	0.3											0.7	0.125
8	0.10795	m										0.8	0.1
9	0.0206375	m											
10	0.000334506	m^2	Wind Vel.	0	knots (in the direction of launch)								
11	20.00	deg	Wind Vel.	0.00	mph								
12	4.25	in	Wind Vel.	0.00	m/s								
13													
14	Pressure [kPa]	Water Velocity [m/s]	Water Mass [kg]	Rocket Mass [kg]	Weight [N]	Thrust [N]	Drag [N]	Angle [deg]	Tx [N]	Tz [N]	Dx [N]	Dz [N]	Fx [N]
15	578.86	29.87	0.998	1.198	11.75	297.89	0.00	20.00	101.89	279.93	0.000	0.000	101.89
16	526.27	28.48	0.898	1.098	10.77	270.83	0.03	20.80	96.19	253.18	-0.011	-0.030	96.17
17	484.32	27.32	0.803	1.003	9.84	249.24	0.13	21.22	90.22	232.34	-0.045	-0.117	90.17
18	449.91	26.34	0.712	0.912	8.94	231.54	0.28	21.51	84.88	215.42	-0.104	-0.263	84.77
19	421.08	25.48	0.624	0.824	8.08	216.70	0.51	21.72	80.19	201.31	-0.188	-0.472	80.00
20	396.50	24.72	0.539	0.739	7.25	204.05	0.81	21.89	76.08	189.34	-0.303	-0.753	75.77
21	375.24	24.05	0.456	0.656	6.44	193.11	1.21	22.03	72.44	179.01	-0.453	-1.118	71.99
22	356.64	23.45	0.376	0.576	5.65	183.54	1.71	22.15	69.21	169.99	-0.646	-1.586	68.56

The overall success of the projectile flight predictor programs led to the production of additional spreadsheet-based programs for use during EDP 3. Like EDP 2, the spreadsheets were built to help students visualize the relationship between the theory taught in class and the performance of their prototypes. The LEGO^{TM} vehicle modeling tool was composed of two spreadsheet-based programs that allowed students to quickly determine numerous variables relating to possible vehicle prototypes to include load force, traction force, maximum propulsive force, and rolling resistance. Additionally, the program contained empirically-determined friction coefficients and rolling resistance data for the various different tires and tracks available to students for construction. Students used all of the data produced by this program to help predict the performance of various vehicle concepts that they had developed during the design process using a morphological chart. Students were then able to choose the best configuration for their vehicle prior to building a prototype by setting up a weighted decision matrix. Ultimately, like the flight predictor programs, the LEGO™ vehicle modeling tool allowed students to quickly visualize how the theory taught in class directly impacted their design decisions.

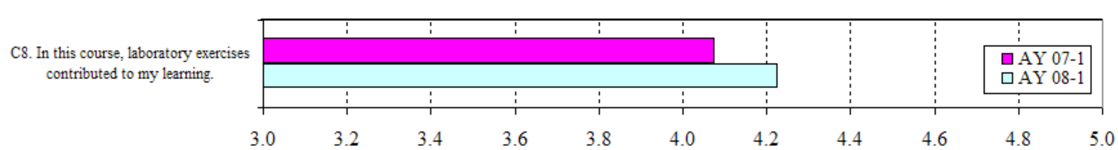
Figure 7. Example of LEGO™ Vehicle Modeling Tool Output



Another important result of the introduction of laboratory exercises was the improvement of student designs when compared to previous years, both in the diversity, originality, and innovation observed in design concepts and in overall design performance. Student design reports submitted consistently revealed a much closer correlation between theoretically predicted and actual results in both the water bottle rocket and the LEGO™ vehicle design competition. This positive change must be attributed almost entirely to the emphasis on understanding and applying the analytical design tools introduced during the laboratory exercises. Providing all student design teams with these same analytical tools and adopting more of a guided approach in the early stages of the design process resulted in more, rather than less, design diversity. As students became more familiar with the physics behind the tools through the practical exercise provided by the lab work, they became more able to generate and evaluate viable and innovative design solutions. Some examples of the various solutions pursued in the water bottle rocket design competition appear in Appendix B. This diversity, while conceptually still present in the LEGO™ vehicle design competition, is more visibly apparent in the rocket design, due to the relatively low complexity of the prototypes. In addition to the increase in design diversity, another universal improvement observed in the LEGO™ vehicle designs was a dramatic increase in reliability during the final competition, with only one vehicle out of 18 failing to remain operational for the duration of the three-minute bout. By contrast, competition bouts in the previous year were eventually shortened to one minute as competing vehicles consistently broke down well short of the original three-minute survival target.

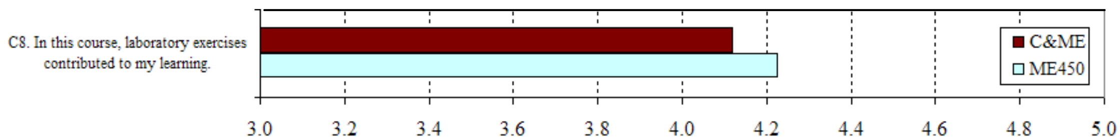
The effectiveness of the laboratories at facilitating student learning was also highlighted by the results of the course end survey. USMA Course-End Feedback is collected using a 5-point scale. Students respond to survey statements by assigning values from 1: Strongly Disagree to 5: Strongly Agree. Historically, it is extremely rare for collective student ratings to fall below 3.0, so the primary area of interest in this scale is the region between 3.0 and 5.0. Within this range, increases or decreases of 0.1 or greater are considered statistically significant. The following survey excerpt indicates that the introduction of the new laboratory activities positively affected student assessment of the course's lab effectiveness, as demonstrated by a 0.15 delta in assessments from ME450 students from Academic Year 07-1 (4.07) to Academic Year 08-1 (4.22).

Figure 8. Course-End Survey Excerpt comparing ME450 student assessments of the effectiveness of course labs in Academic Years 07-1 and 08-1



The positive perception of the new lab exercises was not only demonstrated by the comparison of ME450 student feedback in both Academic Years, but it was also reflected in the fact that the students enrolled in ME450 actually rated the effectiveness of laboratory exercises higher than Civil and Mechanical Engineering majors rated laboratory exercises in their own courses (4.12). This delta (0.10) is more significant due to the fact that it compares an assessment provided by the non-engineering student population of ME450 to that of Engineering Majors in the Civil and Mechanical Engineering Department.

Figure 9. Course-End Survey Excerpt comparing ME450 student assessment of effectiveness of course labs to that of all students within the USMA Civil and Mechanical Engineering Department



Conclusion

By giving students more hands-on interaction with physical examples, and by using a crawl-walk-run methodology to slowly build understanding of the underlying theory, the laboratories created a heightened understanding of the engineering design project problems. This heightened understanding of key concepts such as stability, gear efficiency, traction, and rolling resistance had the effect of promoting a more universal enthusiasm for the application of the engineering design process, as students were forced to realize that successful innovation is not possible without a coherent, methodical approach to problem solving. As students advanced beyond the Knowledge and Comprehension levels of Bloom's Taxonomy and into the higher levels, the quality of their designs began to show a marked improvement over previous years.

Recognizing, however, that the ultimate objective of this course is not to produce LEGO™ vehicles, but rather to enable students to develop lifelong problem solving skills and analytical abilities in accordance with The United States Military Academy Engineering and Technology Goals, the true measure of success is the ability of students to reach the higher levels of Bloom's Taxonomy. As students in ME450 begin to realize that they are capable of true application, analysis, synthesis and, finally, evaluation in an engineering context, their confidence in this realm naturally increases. The key to facilitating this progression lies in the course's ability to link theoretical principles to their real-world applications. The introduction of challenging, hands-on exercises in the form of progressively more complex laboratory events was instrumental in achieving this goal, as demonstrated by comments from the students themselves in the end-of-course reflective essays from this most recent semester.

"On a whole I really thought the course was extremely well organized and executed. There are no real changes I would make in structure or design. Some of the best methods of learning I felt were the labs. The handouts really laid out calculation steps with relative ease and gave me the ability to see the lab as a whole in a neater and more organized fashion than if I had hand-written the calculations on my own."

"I felt like the best techniques were the in class demonstrations and labs. This helped me actually visualize why something worked or how it worked. A great example is the

models of the gears in the class, and the gear lab we did as a class. These helped my learning…"

"I think the hands on learning that took place during the course was the most beneficial. While I hated doing the calculations for the various labs in addition to the work for the projects, I feel that the lessons learned during the labs [were] essential to the understanding of the EDPs."

"The best teaching technique was labs. The labs were a great way to see what we were actually learning in real life."

"I always leave the classes with a greater understanding of the material.... I believe this is due to … a very methodical method to teaching. Starting with the concepts by fully explaining them and making sure everyone understands; and then take the concepts and put them to use through practical problems and practical applications. All this is done step by step, very methodically, so each student follows from start to finish."

Bibliography

1. Lowman, Joseph, *Mastering the Techniques of Teaching*, second edition, Wiley, San Fransisco, 1995, pp. 195-196. Bloom's Taxonomy describes a hierarchy of six levels of cognitive learning, beginning with the ability to recall and recognize information, then incorporating the progressively more complex abilities to comprehend, apply, analyze, synthesize and, finally, critically evaluate knowledge.

2. Headquarters, Department of the Army, *United States Army Field Manual 7-0: Training the Force*, Washington D.C., October 2002, p. 5-3. The military is an often overlooked source of teaching experience and methodology. The crawl-walk-run method is one such methodology: "Ideally, training is executed using the crawl-walk-run approach. This allows and promotes an objective, standards-based approach to training. Training starts at the basic level. Crawl events are relatively simple to conduct and require minimum [outside] support…. After the crawl stage, training becomes incrementally more difficult, requiring more resources…, and increasing the level of realism. At the run stage, the level of difficulty for the training event intensifies. Run stage training requires optimum resources and ideally approaches the level of realism expected in [professional practice]."

3. Headquarters, Department of the Army, *United States Army Field Manual 7-1: Battle Focused Training*, Washington D.C., September 2003, p. 5-6.

Appendices

A: ME450 Stability Lab Handout
B: Examples of Student Water Bottle Rocket Designs

Appendix A: ME450 Stability Lab Handout

LSN 18: Stability Lab PART I (Pre-Lab)

1. Administration: This is a group lab (with a *group* graded submission) designed to give students hands-on experience in modeling and analyzing projectile flight. During the lab, students will record the performance and observe dynamic characteristics projectiles in flight. This lab consists of two sections. Part I will be completed during the lab. Upon completion of Part I, your team will be issued Part II, which will be due at the beginning of class on Lesson 20.

After completing this lab, students should be able to:
1. Use a computer model to predict theoretical aerodynamic performance of a projectile.
2. Validate a theoretical model by correlating actual experimental results with predicted values.
2. Understand and describe the effects of drag and stability on the actual aerodynamic performance of a projectile.

Bonus points will be awarded to the design teams who:

Launch a projectile the longest distance in the section **+5 Points**

Most accurately predict projectile range (closest correlation of theoretical to actual results) **+10 Points**

2. Stability Lab Problem Statement: Optimize projectile performance by identifying and understanding the factors which influence aerodynamic behavior.

The following projectiles will be fired from an elastomeric propulsion device, or EPD (otherwise known as a water balloon launcher):

Poof™ Mini-Football	**Aerobie™ Rocket Football**	**Nerf™ Vortex Mega-Howler**
		
Mass: 72 grams	**Mass: 83 grams**	**Mass: 125 grams**
Diameter: 8.25 cm	**Diameter: 8.25 cm**	**Diameter: 8.25 cm**
Body Length: 14 cm	**Body Length: 14.6 cm**	**Body Length: 15.25 cm**

3. Pre-Lab Assignment (to be completed prior to attending Lesson 18): obtain values for predicted performance of each projectile, using the "football model.xls" spreadsheet. This powerful tool is based on the theory and equations of force and motion that we have covered in lessons 15 and 16.

OBJECTIVE: your objective is to get your projectiles to fly as far as possible, and predict the projectile that will fly the farthest. You may vary the values in any green cell, to include B3 (Launcher Height) and B4 (Launcher Pullback).

Appendix A: ME450 Stability Lab Handout

CONSTRAINTS:

1) The height of your launcher is limited by the height of your group members. You will attempt to re-create these initial conditions during the lab, so do not specify a launcher height that is above what at least two members of your group will be able to comfortably reach and hold. (Take into account the fact that the launcher is capable of generating considerable force!)

2) The launcher pullback length is limited to 90 inches.

MODELING AND ANALYSIS: Once you have input values into every green cell, you can use the "trajectory plot" tab to obtain a graphic representation of the projectile's theoretical flight path. Record spreadsheet data for projectile max height and max range in the table below.

Projectile	**Launcher Height**	**Launcher Pullback**	**C_D (estimated)**	**Max Altitude**	**Max Range**
Poof™	in	in		m	m
Aerobie™	in	in		m	m
Nerf™	in	in		m	m

Bring your data with you to Daly Field (behind the Supt's Box), and be prepared to conduct experimental procedures to validate your models. You may find it useful to bring the football model spreadsheet with you on a laptop computer.

Appendix A: ME450 Stability Lab Handout

LSN 18: Stability Lab — PART II (50 pts)

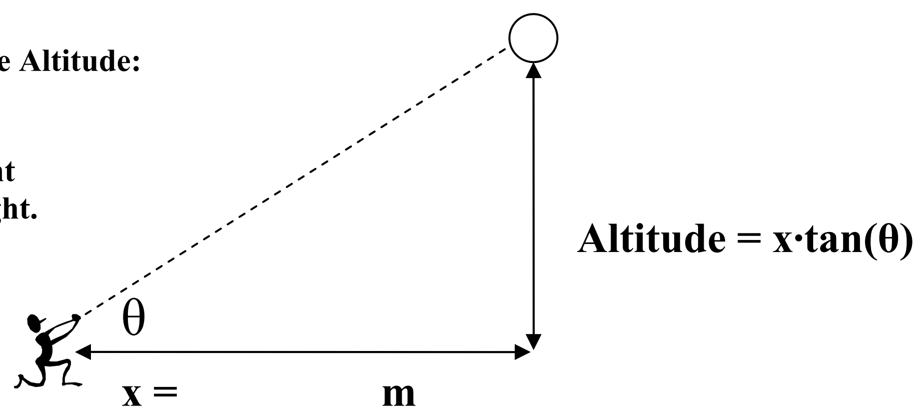
4. **Lab Procedure:** Every design team will launch three types of projectiles using an elastomeric propulsion device (EPD), record performance data, and attempt to vary parameters in order to obtain a good correlation between theoretical and actual results.

5. **Data Collection (3 points):** The following table will be used to record data for each projectile launch. You are required to have data for at least one launch of each projectile. You are authorized up to three launches of each projectile, time permitting.

Football	Launch Attempt	Height (in)	Pullback (in)	Angle 1	Angle 2	Angle 3	Average Angle	Altitude (m)	Range (m)
Poof™	1								
	2								
	3								
Aerobie™	1								
	2								
	3								
Nerf™	1								
	2								
	3								

Method of Calculating Projectile Altitude:

Angle θ, measured from a point perpendicular to projectile flight.



Appendix A: ME450 Stability Lab Handout

6. Observations:

Record observations about the flight characteristics of each projectile when launched (3 points).

Football	Flight Characteristics (Launched)
Poof™	
Aerobie™	
Nerf™	

Throw each projectile by hand, and record observations about flight characteristics (3 points).

Football	Flight Characteristics (Thrown)
Poof™	
Aerobie™	
Nerf™	

Center of Gravity Estimation: using the "string method," identify the approximate location of the center of gravity of each of the footballs below (3 points):

Appendix A: ME450 Stability Lab Handout

7. General Analysis:

Account for differences in your original theoretical results and the actual performance of the projectiles (4 points).

Identify sources of uncertainty in your theoretical model (2 points).

What do you think was your biggest source of uncertainty? Why? (2 points)

8. Drag Analysis

What values for the Coefficient of Drag bring the theoretical performance of each projectile close to the actual performance observed during the lab? (3 points)

Football	**Drag Coefficient**
Poof™	
Aerobie™	
Nerf™	

Are these values reasonable? Why or why not? (2 points)

Comparing the drag coefficient you have now estimated for the Nerf Mega-Howler with the original drag coefficient you were using, suggest a method to predict the drag coefficient of a complex shape (such as a water bottle rocket!—see Table 15-2, and consider both the size and shape the football's body and the size, shape and number of its fins) If your results are similar, explain the rationale you used to obtain your original coefficient (4 points).

9. Stability Analysis

Describe the effects of instability, in terms of the principles of aerodynamics you have learned. What parameters/variables does instability influence, and now does that impact performance? (3 points)

Appendix A: ME450 Stability Lab Handout

Estimate the location of the Center of Pressure for each of the projectiles, using the "simplified calculation of cp" method described on the NASA website below:

http://exploration.grc.nasa.gov/education/rocket/rktcp.html

Using the ruler in the photographs as a scale, record the locations of the center of gravity and center of pressure in terms of their distance from the nose of each projectile. Refer to your Center of Gravity measurements in Part I. (6 points)

Football	Center of Gravity	Center of Pressure	Distance Between CG/CP
Poof™	in	in	in
Aerobie™	in	in	in
Nerf™	in	in	in

Based on your results and observations, what can you conclude about how the relationship between center of gravity and center of pressure affects projectile performance? (2 points)

There are many similarities between the flight of these projectiles and that of the water bottle rockets you must design for EDP2. How can you apply what you have learned to the design of your water bottle rocket? (2 points)

What minimum value for the distance between CG and CP do you think will give you an acceptable level of aerodynamic performance? (2 points)

List at least three methods you might use to in crease your water bottle rocket's stability (hint: consider the differences observed between *throwing* and *launching* these footballs) (6 points)

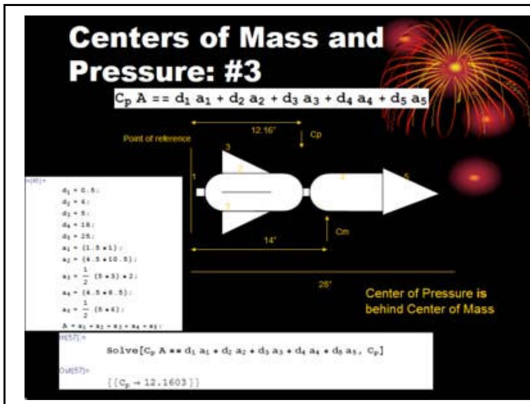
1.
2.
3.

Appendix B: Examples of Student Water Bottle Rocket Designs

This rocket utilizes an extended nozzle system in an attempt to optimize thrust.

Curved fins on this rocket prototype are designed to increase stability by inducing spin, a concept introduced during the ME450 Stability Lab

Durability was the primary objective of this sturdily built rocket. Large fins, coupled with a front-loaded center of gravity, created a large restoring moment to ensure stability in flight.



In an attempt to enhance performance by increasing the volume of the pressure vessel, this team designed a two-stage rocket.

Appendix B: Examples of Student Water Bottle Rocket Designs

Stability is introduced by a streamer in this unconventional design, demonstrating students' ability to apply an understanding of the relationship between center of gravity and center of pressure to develop an out-of-the-box solution.