AC 2011-1287: INITIAL IMPACT OF A FIRST-YEAR DESIGN-BUILD-TEST-COMPETE COURSE

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Initial Impact of a
First-Year Design-Build-Test-Compete Course

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Abstract

For the past six years there have been experimental offerings of a first-year engineering course that incorporated a very extensive design-build-test-compete (DBTC) pedagogy. This course was specifically positioned to exercise core-engineering competencies, communication skills, and creativity. The course is intense in that it involves two Aerospace Engineering team projects, integrated technical communications and technical content, teamwork, and individual scientific and fabrication laboratories. The projects involve design, build, test, and compete cycles with balloons and then with radio-controlled blimps. The students entering this DBTC course and other first-year courses were studied with respect to typical admissions criteria including high school grades and test scores, advanced placement and transfer credit, and extracurricular activities. Performance in subsequent courses was studied by means of grades. Notably, the average student electing the blimp course had lower entering credit than a typical student. Despite this difference, the alumni of the DBTC course had a noticeable increase in their subsequent-term’s grades (~ 1/3 of a letter grade) compared to an average entry student; this improvement in performance was equivalent to the effect of 1-2 Advanced Placement courses from high school and was most significant for students who were admitted with lower entry credit and who later enrolled in the first Aerospace Engineering course.

Introduction

For the past six years there have been experimental offerings of a first-year engineering course—Introduction to Engineering-Blimp Section—that incorporated a very extensive design-build-test-compete (DBTC) pedagogy. This course was specifically positioned to exercise core-engineering competencies: understanding of societal needs and use of scientific and mathematical principles, technologies and fabrication, and communication principles. It also exercises algorithms to solve engineering problems and to develop creativity.

The course incorporates numerous active learning strategies. These include projects, laboratories, lecture-based exercises, individual and team exercises with persistent feedback from both a technical and technical communications instructor. While comparable introductory engineering courses at our institution also incorporate some active learning techniques, most are primarily lecture based. In addition to the active learning techniques and labs, this course has an increase in the regularly scheduled contact hours from 5 to 6, and extensive time commitments outside of class.

In recent years there has been a concerted effort to find means to incorporate active learning techniques into engineering education\textsuperscript{1,2}. This course incorporates some of these active learning techniques, and shares many similarities with other project based-courses\textsuperscript{3,4}. It also appears to have replicated at least some of the enthusiasm and educational benefits\textsuperscript{5,6}.
The impetus for this study is to compare this course against its peers and attempt to identify if there is a quantitative change in the academic performance of alumni of the course. Another motivation has been to quantify anecdotal evidence of changes in the spectrum of the student population taking the course and the means for this change: the number of students taking the course that express an interest in Aerospace Engineering has not been keeping pace with the growth in the course. In particular, in diagnosing team dynamics, we found that students with some type of passion for the activity were mostly like to find the time to be available and participate. We have used course surveys and interviews, but in an attempt to obtain quantitative proof, the input characteristics of the students in the class were compared with their subsequent performance. We found that the most useful method was not to examine the students based upon their scores at the time of matriculation (e.g. High-school grade point average or standardized tests), but by their amount of advanced placement or transfer credit.

We have determined that the input population to the course has changed as the course’s popularity has increased. This has led to displacement of the target first-year Aerospace Engineering population. The course has also been used as an entry-point for students with significantly less than average entry scores. Even with these hurdles, there is a quantitatively significant increase in student performance, especially of those with low-entry credit level, of a magnitude of ~ 1/3 of a letter grade, comparable to the effect of ~ 1-2 advanced placement courses in high school.

**Course Description**

Most of the details of this blimp course have previously been reported. The primary purpose of the blimp course is to serve as an introduction to Aerospace Engineering by means of experiencing the life-cycle of flight vehicles. The course is composed of four instructional threads that are interwoven: (1) a set of technical lectures on relevant foundational scientific principles; (2) lectures and role-playing covering the societal-engineering interface; (3) a series of laboratories covering relevant phenomena, technologies and fabrication; and (4) technical communications lectures, exercises, and products and sufficiently challenging projects that couple all of the interfaces and are completed by individuals and teams of students. Relationships among the first three are illustrated in Figure 1.

The treatment of each interface in this course is extensive enough that it might be considered its own small course. For example, the laboratories have the same format as our 3rd year instrumentation course and are intended to cover a topic broadly. For instance the lab on power systems covers not only the batteries used in the actual Terrestrial project, but also solar cells and temperatures that would be useful for a Martian design. Lectures similarly cover both the technologies and techniques used to build an actual blimp prototype, but use invariance principles to scale vehicles to other environments. One consequence of the interweaving is that typically more than one team or individual assignment is outstanding at any moment, and these assignments can touch upon one or more of the threads.

The blimp course is intense in that it involves two Aerospace Engineering team projects, integrated technical communications and technical content, teamwork, and individual scientific and fabrication laboratories. The two team projects involve design, build, test, compete cycles.
with balloons and then with radio-controlled blimps. Each vehicle is not only designed and built for a terrestrial environment, but scaled to Mars as well. Since the blimp course is experimental, it has been offered six times, only in the fall, in parallel with more typical lecture-based offerings of Engineering 100. Enough students, 364 blimp students vs. 3169 (students taking first-year engineering in the fall, 2004-2009) other students, have been taught in both formats to allow a quantitative comparison of their performance in subsequent courses, thereby offering some insight into the differences in pedagogy.

The first-year Introduction to Engineering courses (Eng 100) all have similar content when it comes to technical communications. Students are required to write reports and give oral presentations, although students in the blimp course do five rather than one or two oral presentations. The main differences between the different sections are the technical content and the instructional pedagogy. The technical content is primarily fashioned by the technical instructor. During its initial three offerings, this was the only first-year Introduction to Engineering course to have a dedicated laboratory. This laboratory is well equipped and has developed into a small learning community where individuals and teams of students have come to study and to socialize. In more recent years, the popularity of the blimp course has spawned attempts to replicate some of its features. These have included a course to study submersibles and one to build a music synthesizer using programmable logic arrays. The submersible course was offered in the same facility as the blimp course, except during the winter term. The synthesizer course was also initially offered during the winter term. As will be discussed later, the winter term has different advising and selection strategies; consequently, these derivative courses were not isolated in this study and left grouped with the traditional courses.

Another factor is the stability of the instruction in the Introduction to Engineering blimp course. The blimp course reported here has had the same technical instructor and almost always the same technical communications instructor. We have successfully repeated the popularity of the course with a different technical communication instructor, and different graduate student instructors covering the laboratories. The demeanor of the graduate student instructor is important to laboratory culture. We have adopted the strategy to hire graduate student instructors that are past alumni of the course. The result of this stability is that variations in instructor styles have been minimized.
Initial Assessment

To illustrate the impact of the course, we can let the students speak for themselves: Three years after they took the course some students, then seniors, presented their view of the course. Their main points are provided verbatim in Table 1. Some of these phrases were promoted during the class. For instance the instructors said “Allow freshmen to become engineers right away”. Consequently, this phrase might have been extracted from course notes. However, there are other phrases that appear to be original and are shown in italics. These include “Spark motivation to succeed”, and others. It is heartening that seniors would have these take-aways years later.

<table>
<thead>
<tr>
<th>Initial Impact</th>
<th>Design-Build-Test-Compete Projects</th>
<th>Technical Communications</th>
<th>Long Term Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduce first-year students to an entire flight vehicle</td>
<td>Team-based project</td>
<td>Based upon student lab experiments and team projects</td>
<td>Teamwork experience -&gt; Leadership in CoE teams</td>
</tr>
<tr>
<td>Allow freshmen to become engineers right away</td>
<td>Tangible functional results</td>
<td>Constant feedback and discussion of progress</td>
<td>Preparation for future Courses</td>
</tr>
<tr>
<td>Spark motivation to succeed</td>
<td>Preview to industry</td>
<td>Better understanding of technical concepts</td>
<td>Networking and practical knowledge for internships</td>
</tr>
<tr>
<td>Encourage lasting student-faculty interaction</td>
<td>Multiple design interactions</td>
<td>Significant improvement over term</td>
<td>Sense of pride and accomplishment</td>
</tr>
<tr>
<td></td>
<td>Complete system integration and engineering as freshmen</td>
<td></td>
<td></td>
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</tbody>
</table>

Our first step toward assessment occurred informally at the end of each class: We interviewed all students. They have been open about aspects of the course they have found valuable and those that need more refinement. We have used this feedback to evaluate the course and ourselves and, consequently, the course has evolved after every offering. In hindsight, given that the course has continued, we should have been more formally recording this feedback. More usual surveys could have been used to quantify this feedback.

Initially, it was not clear if the course would continue from year to year. The course was anomalous in that it required a dedicated (borrowed) lab, supplies, extra instructional support and was being offered to a class that was ~ 1/3 the usual first-year class size. The enthusiasm expressed by the first class was viewed as a result of the small class size, novelty, the hands-on work, and there were doubts if it could ever be scaled up in size or repeated. Instructor efforts were focused on obtaining support, and finding ways to increase the class size.

The course has independently been assessed through usual University of Michigan course evaluation processes, which involve an anonymous questionnaire. The questions involving the course or instructors being excellent are consistently at the top. Anecdotally, we have kept in touch many students and noted that their enthusiasm for the course persists years later, and remarkably, positive comments about this course have started to appear in the surveys of seniors, as shown in Table 2. We have leveraged this enthusiasm in several ways: volunteers to help support the competitions, act as evangelists for the class, and cover evening lab hours. All volunteers come from the class alumni base and have been valuable in growing the course.
Table 2. Responses to “What was your favorite course?” that mention the Engineering 100 blimp course in the Aerospace Engineering Senior Surveys.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Students</th>
<th>Responses</th>
</tr>
</thead>
</table>
| 2007-2008  | 15                 | • … it did the best job of combining engineering with technical communication with laboratory work with design/build/test.  
• It was the first time I got to be an engineer, right out of high school, and we made blimps, which was more than I can say for most subsequent classes. |
| 2008-2009  | 20                 | • Professor ---- was extremely passionate about the course and it was one of my first experiences in a design, build, test type project.  
• … making blimps from scratch, and having to develop every system our selves was an incredible experience. |
| 2009-2010  | 30                 | • … exposed students to lab tools, and design process right away. Problem solving skills enhanced  
• … He taught the basics of engineering through hands-on experience as well as theory. This class got me truly excited in aerospace.  
• It was free reign to design what we wanted with a very interesting (blimp) infrastructure. There was little formal teaching and more dealing with real life issues the first semester of college.  
• … the professors were very involved, the labs were comprehensive, sections were small, and we applied what we learned into a fun team project  
• Gave a good introduction to all aspects of aerospace engineering, with good integration and execution of design/build/test, introductory theory, and technical communications. |

The course helps foster an enthusiasm when it is taught that can persist for the duration of a student’s program of study. The core question here is if the course is just about excitement and good feelings, or if there is some quantifiable benefit.

Population Size

The College of Engineering at the University of Michigan has a typical first-year undergraduate enrollment of over $10^3$. All of these students take a first-year Introduction to Engineering course (Eng 100) either their first or second term in residence. In the alternate term, they are taking a first-year computing course (Eng 101). Approximately $\frac{1}{2}$ of each class is enrolled in each first-year engineering course in the fall term. This format has been stable and ensconced for the past decade. This annual enrollment is shown in Figure 2.

It is important to note that all students enter into Michigan’s College of Engineering without declaring a major. Once students have passed the first term and remain in sufficient academic standing, they can declare into a variety of programs. Consequently, the students who are enrolled in any first-year course may have a strong to weak interest in any particular topic. Since the first offering of the blimp course, the instructors have held informal exit interviews with each
student and student team. One of the questions has always focused on future academic plans, and there are at least two populations in the course: Those that have a passion for their vehicle, and those that have other interests. We discovered that even while we were growing the course, the percentage of students interested in Aerospace Engineering was not consistent, and a significant portion of the students were interested in other majors.

The target population for the blimp version of the first-year Introduction to Engineering course is nominally students who are interested in the Aerospace Engineering program. This program has \( \sim 10^2 \) student entering on an annual basis. Since Aerospace Engineering is multidisciplinary, the blimp course has features that touch upon Mechanical and Electrical Engineering, as well as Atmospheric and Material Sciences, and it has many features relevant to Marine Engineering.

The target size of the initial offering of the Blimp course was 30 students, which allowed the course to be refined as the term progressed. This decision to start small turned out to be very valuable and exposed logistical weaknesses in the class. For example, each of the 6 teams in this first course built numerous blimp envelopes and gondolas that needed to be stored in the lab facility. In later offerings, we required the blimp system to be collapsible onto shelves to allow compact storage. The course grew to 100 students by the fall of 2009. This was accomplished by splitting the lectures and labs, thereby appealing to two groups of students with different schedules allowing fuller use of the lab. This enrollment of 100 was significant because it was of comparable scale to the target population.

**Student Preferences**

The students do not generally select a particular course out of an elective pool at random. A potentially significant factor is the self-selection based upon student interest. The common wisdom for our College of Engineering (CoE) is that about one third of the students know their intended field of study at the time of entry, about one third think that they do but change, and
about one third do not have a preference at the time of entry. Thus, approximately two thirds of CoE students find their path to a major once they are present. This common wisdom is supported by Table 3, the results of a senior survey attempting to ascertain when a student decides to declare a major. The “Overall CoE” results indicate that less than 40% of students have identified a major before arriving at the University of Michigan. Thus, the results support the notion that some type of uniform or program-neutral first-year is appropriate for the majority of our students. Indeed the whole first-year program is configured around this assumption.

However, the results are not uniform across all programs. There are some programs where the students know what they want to accomplish early, notably in Aerospace and in Nuclear Engineering. Approximately two thirds of Aerospace students know what they want to do at the time of entry to the University.

Table 3: Results from the University of Michigan College of Engineering (COE) 2008-2009 Undergraduate Senior Survey. (AOSS results from 2006-2007 Survey).

<table>
<thead>
<tr>
<th>Program</th>
<th>Year of Program Decision (% of Students)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before first year</td>
</tr>
<tr>
<td>Nuclear Engineering and Radiological Sciences</td>
<td>82</td>
</tr>
<tr>
<td>Aerospace Engineering</td>
<td>63</td>
</tr>
<tr>
<td>Computer Science from College of Engineering</td>
<td>59</td>
</tr>
<tr>
<td>Biomedical Engineering</td>
<td>51</td>
</tr>
<tr>
<td>Computer Science from College of Literature, Sciences &amp; Arts</td>
<td>50</td>
</tr>
<tr>
<td>Interdisciplinary Engineering</td>
<td>50</td>
</tr>
<tr>
<td>Computer Engineering</td>
<td>42</td>
</tr>
<tr>
<td>Environmental Engineering</td>
<td>42</td>
</tr>
<tr>
<td>Naval Architecture and Marine Engineering</td>
<td>40</td>
</tr>
<tr>
<td>Overall CoE</td>
<td><strong>39</strong></td>
</tr>
<tr>
<td>Mechanical Engineering</td>
<td>38</td>
</tr>
<tr>
<td>Electrical Engineering</td>
<td>37</td>
</tr>
<tr>
<td>Atmospheric and Oceanic Sciences (AOSS)</td>
<td>33</td>
</tr>
<tr>
<td>Chemical Engineering</td>
<td>32</td>
</tr>
<tr>
<td>Engineering Physics</td>
<td>25</td>
</tr>
<tr>
<td>Civil Engineering</td>
<td>23</td>
</tr>
<tr>
<td>Industrial and Operations Engineering</td>
<td>21</td>
</tr>
<tr>
<td>Material Science and Engineering</td>
<td>6</td>
</tr>
</tbody>
</table>

For another view of when a student decides to declare a major and to corroborate the results from the senior survey, the College of Engineering asks first-year students to rank up to three areas of study in which they are interested. Figure 3 shows these results for students interested in Aerospace Engineering. Approximately 70% of students who ultimately pursued an Aerospace degree expressed an interest in Aerospace before they arrived as did the students taking the first four offerings of the blimp course, a trend also noted by the blimp course instructors in student interactions and in interviews. As the course has grown in size, there has been an increase in the number of students without any interest in Aerospace. Only one half of the students enrolled in
the 2008 and 2009 courses indicated any preference for Aerospace Engineering. The explanation frequently given is that that students are drawn toward the design-build-test-compete pedagogy of the course, not the Aerospace material. The instructors hypothesize that this ambivalence toward Aerospace might explain a small but new amount of absenteeism and some less enthusiastic team members.

![Graph](image)

**Figure 3:** Interest in Aerospace Engineering as a function of year. This indicates that at the time of matriculation, the student expressed interest in the Aerospace program. Students in the College of Engineering (CoE) •; students that later enroll in the first undergraduate Aerospace course, (Aero) ■, all in the first-year course (Blimp) □; and alums of the first-year course that also later enroll in the first Aerospace course (Aero + Blimp) ○.

One of our goals in this research is to understand the students taking the course. In trying to understand why increasing numbers of students are not interested in Aerospace Engineering, we discovered a number of factors affecting the selection of the course by students.

First, we discovered that along with our curricular refinements, the first-year-advising office had been modifying how students entered the blimp course. The course has always been advertised as extensive and more work than other first-year courses. We had expected students to simply self-select into the course, and in fact, some of the students sought out the course because it aligned with one of their passions (e.g. flight vehicles), and some were attracted to the hands-on aspect, while a very few reported the course simply met their schedule.

However, other significant factors affected enrollment, including how the limited openings in the blimp class were metered out to the incoming class, how students were advised, and how the course was advertised. First, during the first offering of the blimp course, the instructors noticed that there were zero under-represented minorities in the class. This was traced to how the class was made available: All seats were made available during the first day of orientation. Orientation occurs over several months during the summer, and the seats were filled within the first two weeks when relatively few minority students are registering, so there were biases in the orientation and registration process. To remedy this problem in subsequent years, the seats were
metered out during the entire period of orientation, resulting in student populations that were comparable to College of Engineering or Aerospace Engineering norms.

Second, unbeknownst to the instructors, by 2006 and especially in 2007 the course was being advertised with a video of the final blimp competition. None of the other sections had such an appealing display, so we speculate and have much anecdotal evidence that this led to an increase in the number of students taking the class who were not interested in Aerospace Engineering but who thought the blimp course would be “cool” or exciting. Another factor that was discovered during this study was that the advising office was specifically holding seats open for less prepared students they thought would benefit from the course. Because the course is popular, and there is significant support for students with problems, this type of selection is not unreasonable. However, the instructors discovered the factors of “coolness” and lower preparation after the fact when trying to diagnose an increasing number of individual or team problems, and these factors were very noticeable in the interviews we conducted: Some students had no intention of ever pursing the primary or related disciplines, or they expressed a marked ambivalence towards their final flight vehicle.

A final conclusion from the data in Table 3 and Figure 3 is that while a common first year might be appropriate for the two thirds of the students who find their way to a major once they arrive at the University, a purely common first year puts students who know what they want to do at a disadvantage. Thus, the common first year might be improved to encourage Aerospace and Nuclear students to start some aspects of their program-specific studies early. In other words, if the results in Table 3 and Figure 3 can be used to support the notion of a common first year for the majority of our students, they can also be used to support the notion that some programs are different and do not necessarily benefit from a common-first year. We should allow students who know what they want to do to pursue their majors from the beginning.

**Entry Profiles: Quantitative Comparison of Population Types**

The students entering the design-built-test-compete blimp course and the other first-year Introduction to Engineering courses were studied with respect to typical admissions criteria including high school grades and test scores, advanced placement and transfer credit, and extracurricular activities, and the results appear in the rest of this section. Performance of the various first-year Introduction to Engineering students in subsequent courses was studied by means of grades in the subsequent courses, and those results appear in the next section on Exit Profiles. Notably, the average student electing the blimp course had lower preparation than did students in comparable courses.

The next two figures are two measures of preparedness—by means of advanced placement or transfer credit brought into the University—of the incoming class. Figure 4 shows the number of students with any credit at the time of matriculation as a function of year, and Figure 5 displays the mean amount of credit as a function of year.
As shown in Figure 4, the College of Engineering average is that \( \sim \) 85% of the students arrive with some type of credit, and the average is slightly higher for students who bring in some type of credit and ultimately enter into Aerospace Engineering. By this credit metric, the students in the initial offering of the blimp course in 2004 were exceptional: 90% of them had some type of credit, and 94% of those who went into the first Aerospace Engineering course had some credit. Those in the next offering in 2005 were comparable to Aerospace norms and above College norms. However, starting in 2006, the preparedness of the students had started to drop, and by 2007 only 68% of the students had some credit, well below both Aerospace and College norms.

The mean credit plotted in Figure 5 shows a similar result. The initial students in 2004 who went on into Aerospace Engineering had an elevated amount of preparation, while the later students came to the course with less credit. By 2005 and 2006, blimp students entered with the equivalent of one Advanced Placement course less credit than the College mean and by 2007 with the equivalent of two Advanced Placement courses less credit. These results are statistically significant in that the one standard-deviation error bars do not overlap.
In later terms, the instructors noticed an increasing number of strange errors on assignments and exams. For example, students would take a simple algebraic equation like Ohms’ law: \( V = I R \) (where \( V \) = Voltage, \( I \) = Current, and \( R \) = Resistance), and make simple algebraic mistakes. For example given \( V \) and \( R \), a few would solve for the current as \( I = V R \). This led to a study of the student’s basic math preparedness. A graph showing the fraction of students in remedial math (Math 105) as a function of year is shown in Figure 6. This figure shows that the fraction of students in remedial math is higher (usually more than double) in the blimp course than in the overall College of Engineering, and is usually 3-10 times higher than in those electing Aerospace Engineering as their major.
To the instructors’ astonishment, not only were there significant numbers of students in the Engineering College in remedial math (~ 5%), a greater proportion were in the blimp course (~ 12%). Remedial math here is defined as pre-differential calculus. Students are admitted and during orientation they are asked to take a math placement exam. Based upon this exam they are advised to take a certain math course, and advised in their selection of either the first-year Introduction to Engineering course or the first-year introduction to computation. Students who perform well on this test are encouraged to take their first-year computation course in the fall, and those who perform poorly are advised to take the first-year Introduction to Engineering course in the fall. This would account for about 10% of all first-year engineering classes in the fall terms having students with some type of poor background in mathematics.

In addition to this bias for all fall classes to accommodate students in remedial math, there was also an advising bias for the blimp class. Advisors were placing certain at-risk students into the blimp class because the class necessarily has small lab sections, which facilitate identifying student problems and providing help, and many of these at-risk students accepted their advisor’s recommendation because they had already heard about the class in a pre-collegiate program. The precise details of how this advising occurred is not clear, but we attribute this to be the mechanism for the about 2% additional remedial math students in the blimp class.

The information on the remedial math populations was brought to the attention of the admissions office in 2008 and—by 2009, which provides the most recent data point—there is only a single student taking remedial math. This is a marked drop-off in the remedial math population and indicates that this study is itself perturbing the system.

From our interactions with students throughout the term and in our interviews, we’ve noticed a large disparity the motivation, preparedness, and general organizational capability of the students. In an attempt to quantify some of this from existing data, we have defined the concept of entry credit. Here, entry credit is advanced placement and transfer credits brought into the University minus any remedial math credits required at the University. We hypothesize that entry credit is a measure of preparedness, and perhaps other properties, and we used entry credit as a basis to study other parameters. One such comparison is shown in Figure 7, which shows the relationship between the amount of entry credit and the number of extracurricular activities. For example, if someone were on sports team for each of the four years in high school then this would count as four extracurricular activities. The collection of activities is broad and includes student-government, bands, orchestras, or clubs.

To our surprise, there is a strong correlation between the amount of entry credit a student brings from high school and the number of extracurricular activities a student pursued in high school. The number of extracurricular activities is proportional to the number of entry credits, with a proportionality constant of about 1:4. What this means is that the students who are arriving with significant entry credit are simultaneously those students who engaged in many extracurricular events, and that students with almost no entry credit and also reported no extracurricular activities. We and other faculty find this data very curious and as yet unexplained, although high school and college counselors we have consulted find this data unremarkable.
Figure 7: Number of extracurricular activities as compared with the number of entry credit. Students in the College of Engineering (CoE) , excluding students in the blimp course, and students in the first-year course (Blimp)

Our take-away of all of this data is as follows: (1) there were filter mechanisms at work that influenced the type of student in the class; (2) the students we have been serving in the blimp course have in many cases been below College norms when it comes to entry credit and were on average less engaged in extracurricular activities in high school; thus, they are likely less prepared than most students to cope with the increasing time demands of college.

Exit Profiles: Quantitative Comparison of subsequent performance

To ascertain if the blimp course has some quantifiable benefit, we compared the 2004-2009 students who took their first-year Introduction to Engineering course in the fall of their first year. We used the 2004-2009 database because 2004 was the first year that the blimp course was offered, and we do not yet have follow-up data for students past the 2009 year. We studied the fall students to remove the overt bias of how students are filtered for their math background, and to allow the comparison of the winter term grades. Because essentially all students who took the Introduction to Engineering course in the fall term took the computing course in the winter term, the winter term grades include the grades in the first-year computing course for these students.

The winter term grade point average occurs in the term following the first-year Introduction to Engineering course and is compared against a student’s minimum of their entry scores as shown in Figure 8. The winter term grade point averages are plotted on a 0 to 4 point scale. The student’s entry scores are determined as follows: take the high-school grade point average and any admission tests (e.g. SAT, ACT), and normalize each to 1; out of this collection, select the minimum, which is the students’ worse score. This is the minimum of entry scores. We used this measure instead of the student’s maximum score, because if we took the maximum, every student would have a result in the vicinity of 1 and the subsequent plot would be about a vertical line.
Figure 8 shows that a College of Engineering student’s worst entry score is a weak predictor of an individual’s subsequent second term academic performance. When a students’ worse score was greater than 0.9, then no one with this attribute received a grade below a C (or a grade point average of 2.0). However, there are students who have entry scores less than 0.6 who passed (earned at least a 2.0 grade point average) or received full marks, and students with entry scores of less than 0.5 or even 0.4 who do very well. The blimp students are also shown in this figure (as red circles) and appear comparable to their college peers. Please note that there are zero students in the blimp course with perfect entry scores.

In an attempt to glean more information from this plot, we examined the means of the populations and these are shown in Figure 9. For the College, the means show that there are not huge differences among most students. The blimp students have statistically similar performance to non-blimp students, except at a minimum entry score of ~ 0.68 were there is an improvement of about one third of a grade for the blimp students. Similarly comparing all students in the first Aerospace course with students from the blimp course who are also in this course, all of the mean grades for the blimp students except one are above the mean grades for non-blimp Aerospace students in the class. Some of these points are statistically significant and correspond to about one third of a grade. However, at a minimum entry score of ~ 0.63, the blimp students are below their peers by about one half of a grade. This point corresponds to an interesting and unexplained upswing in the non-blimp dataset. When examining the winter term grades in comparison to entry score, there is at best a small improvement in some of the grades for the alumni of the blimp course, but there is not a clear trend.
Figure 9: Mean winter term grade point average as compared to the minimum of entry scores. Restricted to students taking first-year Introduction to Engineering in the first fall term. Error bars represent the one standard deviation of the mean. Students in the College of Engineering (CoE) •, excluding students in the blimp course, and students in the first-year course (Blimp) ○ (left). Students that later enroll in the first undergraduate Aerospace course, (Aero) ■, and alums of the first-year course that also later enroll in the first Aerospace course (Aero + Blimp) □ (right). (*) indicates a single data point.

An alternate view of the data is to compare the grades based upon a student’s entry credit. The winter term grades with respect to a student’s entry credit is shown in Figure 10. There is a significant improvement for blimp students who come to college with no or low amounts of credit (less than 10 credits). The magnitude of the improvement is approximately one fourth of a grade. Everywhere else, there is not enough data from the blimp students to be statistically significant.

Figure 10: Mean winter term grade point average as compare to entry credit.Restricted to students taking first-year engineering in the fall term. Error bars represent the one standard deviation of the mean. Students in the College of Engineering (CoE) •, excluding students in the blimp course, and students in the first-year course (Blimp) ○ (right). (*) indicates a single data point.
It is not clear if the winter term (second term) grades are a good assessment of the first-year Introduction to Engineering course. In the second term, students are taking an introduction to computing, math, and either chemistry or physics: These are not second Introduction to Engineering types of courses. One hypothesis for any increase is that it might be a measure of the life-skills taught in the blimp course. Since there are multiple interwoven assignments each week, students are forced to get organized and plan.

Since the target audience of the first-year Introduction to Engineering blimp course is Aerospace Engineering students, we studied the students who eventually took the first course in the Aerospace program (Aero 245). Student grades in this first Aerospace Engineering course appear in Figure 11 with respect to the students’ entry credit.

![Figure 11: Mean grade in the first Aerospace Engineering Course (Aero 245) as compared against entry credit. Restricted to students taking first-year Introduction to Engineering in the fall term (left) and all Aero students 2004-2009 (right). Error bars represent the one standard deviation of the mean. Students that later enroll in the first undergraduate Aerospace course, (Aero) ■, and alums of the first-year course that also later enroll in the first Aerospace course (Aero + Blimp) □. (*) indicates a single data point.](image)

Aero 245 is typically only taken by students intending to pursue an Aerospace Engineering degree, and is taken during the 2\textsuperscript{nd} year (in either the 3\textsuperscript{rd} or 4\textsuperscript{th} term in residence). This covers the performance of air and space vehicles and involves some technical communications in the form of reports. Consequently, it contains both engineering and communications content and covers both significant features of the blimp course. Blimp course alumni entering this subsequent course displayed improvement over other entering students. The improvement is most readily apparent for students with low entry credit, and in some cases the improvement was significant: from ~1/4 to ~1/2 of a grade. This improvement remains even if the blimp alumni are compared against all Aerospace engineering students (students that took their first-year course either fall or winter term). For higher levels of credit, there is insufficient data to claim significance.
Discussion

We have found that students in the blimp course do somewhat better than their peers in other Introduction to Engineering courses, especially students with relatively low numbers of advanced placement or transfer credits or those with lower math preparation.

We hypothesize that the impact of this blimp course may be partly or largely traced, as expected, to features of the design-build-test-compete (DBTC) components of the blimp course, including the use of many active-learning techniques and the extensive hands-on labs and two projects. However, we hypothesize that the impact is also due to the interaction of many other features of the course: a fast start-up to the course necessitated by the team projects; the multiple assignments due each week and the resulting need to develop better time-management skills to complete them; the passion and interest many students have for the subject of the course; the high level of interaction between students and faculty and the development of long-term interactions (indicated by students keeping us informed of their progress and seeking letters of reference long after the course); the development of a learning and social community in the course, fostered by the dedicated lab space; the integrated systems view of engineering presented by the course through the integration of the four major course threads (foundational scientific principles, the societal-engineering interface, technology and fabrication laboratories, and communication and challenging projects work requiring teamwork); and a teamwork debriefing component that occurs throughout the course.

We hypothesize that many of these aspects of the course lead to improved time-management skills, teamwork skills, and high-level planning skills in our DBTC course that increase student performance in subsequent terms over that from other non-DBTC Engineering 100 offerings. These findings persist even when controlled for commitment to major: first-year students choose and stay with their major in Aerospace Engineering at our university at the 75% level, rather than the more usual 35% level. The DBTC model alone does not lead to the improvement in student performance, and it is very difficult to separate out the effects due to the DBTC model from those due to other features.

There are other course selection issues that may affect the students who elect the blimp course and their subsequent performance: Do students take easier classes or fewer classes because of the extra work advertised for the blimp class? We have performed some limited personal checks on the data to search for these other issues. There is exactly one student who had no advanced placement or transfer credit, was in both remedial math and the blimp course, and went on to study Aerospace Engineering. This student recently graduated with both a Bachelor’s and Master’s degree from the University of Michigan. Both instructors know this student very well and approached him with this observation. His explanation was that at the time of orientation he didn’t perform very well on the math placement exam and was given the choice of either going into remedial math or the usual first-term calculus. He explained that he selected remedial math because he had registered for the blimp course, which had been advertised as more work, and to have some relief in his schedule he chose the more basic and easier math class. Ultimately, he felt it was a poor decision because he ended up tutoring his remedial math class. We have so far found no additional evidence of students taking less credit to be in the blimp course, but we have yet to determine if there are other cases of students taking lower-level courses to make more time
for the blimp course. For example, a student might elect to take regular physics over honors physics because of the enrollment in the blimp course.

It is sobering to look back at an almost decade-long endeavor (from inception, though development, instruction, and this study), and to come to grips with the difficulties of extracting numerical proof of any impact. The noisy data, coupled with the 1.5-year delay to obtain a performance measurement (time from first-year course to first course in Aerospace Engineering), and the correlation with entry credit, served to limit the number of students in each population and thereby infringe upon the statistical relevance. Other correlations were examined but did not have sufficient numbers to make observations relevant. For example, since the blimp course has a large component of technical communications, it is natural to wonder if the technical or non-technical aspects of the course are most important. Students enter with a wide distribution of both technical backgrounds (e.g. Math, Physics, Chemistry, Biology), and non-technical backgrounds (e.g. History, English, or other languages). There was insufficient data to determine if either of these groups benefited more or less from this course.

Similarly, we have partially accounted for how students arrive into the course. To a certain degree, the study of entry credit indicates industriousness or other motivational features. However, we still cannot completely rule out some selection explanation.

In the future, some aspects of this study will be more challenging to continue in its current form. The entry-level Aerospace Engineering course has been replaced by two courses. One course is heavily weighted towards technical communications, while the second is mostly technical. The instructors have also asked the first-year advising office to populate the course with students who have some demonstrated interested in a field associated with Aerospace Engineering. This will hopefully cause an upswing in the level of interest measured in Figure 3, and improve some of the team dynamics.

A word of caution is that it is not at all obvious if the definition of terms here and in the literature is completely consistent. For example, in the literature, the word “project” can either mean a focused and relatively simple activity, or a diffuse and complicated one. In our case, each lab in the course contains what could be called small focused projects/activities that are completed either by individuals or pairs of students; we call these “activities” as distinct from longer and more complex projects. This distinction is not always present in the literature.

The disparity in the definition of the term “project” has become clear in our informal comparisons of this course with some of its descendants. For example, one descendant was taught with a format that mirrored this course quite closely. Rather than build balloons and blimps, students in that course built a bathysphere and a remote-controlled submersible. Strangely, the week before their competition the lab was empty, and the instructor explained that everyone had finished. The contrast with the blimp course is striking. No team has ever come close to finishing its blimp the week before. The two weeks before the blimp competition the lab is populated with teams of students late into the evening and throughout the weekends; the instructors literally have to ask students to leave and go home. This is a major place where the teams and the class bond into a shared sense of purpose and camaraderie and illustrates what we mean by an encompassing and engaging project that can be measured by the student enthusiasm:
the students would rather be working on their blimps than participating in other activities, including sleeping.

**Conclusions**

We have conducted a relatively large-scale study of students in six years of offerings of a fall-term, design-build-test-compete, first-year Introduction to Engineering blimp course; determined the entry characteristics of the individual 364 first-year students in the blimp course and the 3169 fall term students not in the course; and determined the subsequent performance of both sets of students by their second semester grades and by grades of a subset of the students in the first course in Aerospace Engineering. We correlated the performance of all students studied with their preparation for college as measured by the advanced placement and transfer credits they brought to the University and by their need for remedial math. We also studied the confounding factors of student interest in a particular field (Aerospace Engineering), changes in advising and advertising of the course, how seats were allocated during registrations periods, and the impact of the course on entry criteria and advising over the years.

We have found that students in our fall first-year blimp course involving integrated projects, technical assignments, technical communication, and laboratories have improved academic performance over their peers in their second term at the University. The magnitude of this improvement is ~1/3 of a grade. This improvement is most pronounced for students with the least preparation, and corresponds to the benefit conferred by 1 to 2 high-school advanced placement courses. For other students, there was not sufficient data to see a compelling difference. Blimp course alumni entering the first department course in Aerospace Engineering also displayed improvement over other entering students. The improvement is most readily apparent for students with low entry credit, and in some cases the improvement was significant: from ~1/4 to ~1/2 of a grade. Despite an evolution both in the course and in how the course is populated, the improvement persists.

No single factor has been isolated to explain the improvement. The course immerses the students in an engineering environment and a social and learning community and is very highly rated by the students. There is some anecdotal evidence that the enthusiasm for the course is related—as expected—to this immersion in an engineering environment and to active-learning and hands-on and design-build-test-compete (DBTC) aspects of the course. However, there is also anecdotal evidence that this enthusiasm is related to other factors: to student self-selection, their passions for the field of study, logistical features and systems view of the course, and the high level of interaction between students and faculty during and after the course. In short, the course provides a rich learning environment on many levels, and it is hard to tease out the effects of individual components of the course.
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References


[10] Developed in consultation with Leland Nicolai, currently with Lockheed Martin Advanced Development Programs, 2004
