AC 2007-2771: IMPACT OF NEW FACILITIES ON ENGINEERING STUDENT OUTCOMES

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Abstract

Embry-Riddle Aeronautical University (ERAU) has established a reputation for providing undergraduate students with a curriculum which has a strong emphasis on application based learning. In an effort to improve this learning environment, the campus has recently added a 20,000 square foot Aerospace Experimentation and Fabrication (AXFAB) building dedicated to providing undergraduate students with a premier laboratory facility. The building was designed using faculty input to ensure that it best meets the needs of the courses with experimentation content. As the name implies, the building not only includes laboratories, but also a fabrication suite which students use to construct test articles that form the basis for their experiments. Within this framework, the building is equipped with state-of-the-art tooling and laboratory apparatus, thereby creating a modern environment similar to what would be found in industry.

This paper discusses the impact the improved facilities have had on student outcomes as defined for various laboratory and design based courses, and how these correspond to the outcomes defined by ABET. The intentional design of the building to create a spacious environment which allows students to work safely with industry standard equipment is recounted. The impact on student learning in each of the laboratory courses which make use of the facility is defined both qualitatively and quantitatively. A special emphasis is placed on the impact on student learning in the senior capstone courses, which involve the fabrication and testing of aerospace systems and assemblies, and the improvement in timely instruction as the students transition to the workplace. Also discussed is the improved ability for faculty to perform undergraduate research and improve the learning environment outside of the traditional classroom setting. The paper concludes with a summary of the overall improvement in the undergraduate learning environment and proposed curriculum improvements which are directly tied to new facility.

Introduction

The following sections provide insight into the improvement in ERAU student outcomes resulting from the addition of new facilities resident in the AXFAB building. These outcomes are defined by the College of Engineering in accordance with ABET a-k criteria. The particular outcome which is most directly impacted by the new facilities states: “All engineering students will be laboratory and computer proficient with modern equipment and current laboratory and computer methods.” The impact on student outcomes for individual courses will be discussed on a course-by-course basis.

The paper begins with an overview of the AXFAB facility, which provides the chronological sequence of events that led to the realization of the new building. This section also describes how the building design was driven by faculty needs for experimentation-based courses. The subsequent sections provide a course-by-course review recounting the impact of the new facility on the courses where it has had the most influence. The paper concludes with a summary of how the facility has impacted the students’ ability to mesh theory, computation, and experimentation...
and a discussion of planned curriculum improvements now made possible with the addition of the new amenities.

Building Overview

The AXFAB building is a 20,000 square foot facility that combines state-of-the-art laboratories with a fabrication suite providing manufacturing and rapid prototyping capability. The impetus for the development of this building began with an Aerospace Engineering (AE) department self-assessment completed in 2001 in preparation for an ABET audit conducted in 2004. This internal self-assessment indicated that the condition of the labs and their adequacy for instruction ranged from poor to good. These findings led to a revamping of the College of Engineering Outcomes & Objectives (O&O’s), and made the allocation of funds for facility improvement a higher priority.

From the Fall of 2001 to the present a number of events have aligned to enable our facilities development; including the development of new ABET O&Os, support of the AE Industrial Advisory Board (IAB), and support of the administration. When the department presented the results of the internal self-assessment to our IAB in the Fall of 2001, our newly-hired Dean of Engineering and IAB indicated that improvement of our facilities should be given the highest funding priority. The new Dean and IAB Chair provided an evaluation which corroborated the observations documented in the 2001 self-assessment. This proved to be instrumental in garnering the support of the Chancellor and University President, and led directly to the plans for the new building.

During the 2004 ABET visit, the department was able to show the visiting team new facilities along with broken ground for the new building. The potential for improvement in student outcomes was duly noted by the ABET auditors. The resulting improvement in morale among our students and faculty is contagious. In fact, the most recent alumni survey indicated a 100% satisfaction level with engineering facilities, even though those responding to the survey graduated before completion of the AXFAB building. The engineering faculty have indicated that the new facilities are already making a difference in our department outcomes, as will be further documented in subsequent sections.

An important step in the development of the building was a survey conducted of the faculty who taught experimentation or design based courses that would likely make the most use of the facility. Each was asked to provide a schematic of how their particular lab should be arranged, with all desired equipment noted. This information was collected and utilized in creating the final building layout, ensuring that adequate space, power sources, and ventilation were accounted for in each area. Much of the requested equipment was included in the funding of the building, thereby ensuring that the facility would be functional shortly after building completion.

The building was completed during the Spring 2006 semester and became fully functional in Fall 2006. It contains a Space Systems Lab that houses an air bearing and vacuum chambers, a Materials Lab with adjacent scanning electron microscope room, a Structural Dynamics Lab containing a shaker table, a Structures Lab that includes a 150 kip reaction frame, a Mechanical Testing Lab with load frames suitable for coupon testing, and a Structures and Instrumentation
Lab. The fabrication suite includes an 1800 square foot Machine/Wood shop that includes a computer numeric controlled (CNC) Bridgeport Mill and two fabrication areas dedicated to aeronautics and astronautics capstone courses. An area dedicated to rapid prototyping using three dimensional printers is located adjacent to this fabrication suite. Two small classrooms are included in the building to facilitate the learning environment for the laboratory-based courses, and two research areas are dedicated for use by students involved with undergraduate research projects. The building’s floor plan is shown in Figure 1, below.

Figure 1: AXFAB Building Floor Plan
As shown in this figure, all laboratories are located only steps away from the fabrication suite to allow students easy access to the tools necessary to produce the subject of their experiments. Also shown in the figure is the 3600 square foot Service Yard adjacent to the Machine Shop and Structures Lab. This outdoor area allows for storage of equipment and material and facilitates the importation of large items to those locations.

Three photographs of the building are provided in Figures 2 and 3, below.

As these photographs show, the afore-mentioned facilities are integrated into an aesthetically pleasing and spacious building which makes use of natural light wherever possible. The following sections will discuss the impact of these facilities on the individual courses which are most impacted by them.
College Success

At ERAU, first-year engineering students are required to take a "College Success" course in their first semester. Feedback from this course was often lukewarm because students wanted to have more professional-related information. During the Fall of 2006, the instructors for this course introduced tours of the new facilities and selected a team-based design/build/compete project as a way to provide more focus on engineering. The new building and other additions to our lab facilities made for an impressive introduction for our students. Students commented that they really enjoyed seeing demonstrations of some of the equipment and wanted to see further demonstrations. In the end-of-semester course evaluation, the lab tours and demos were the only part of the course that the students were unanimously in favor of.

For the design/build/compete project, students utilized the new senior design fabrication facility in the AXFAB building to fabricate their designs. The competition featured many innovative projects as well as the expected failures and last minute fixes. Feedback was very positive on this project as it was being implemented and most of the comments in the "additional comments" end-of-course evaluation were related to the project. While most of the comments were favorable, some students suggested a different project. Other feedback mechanisms in this course were the student mentors, called Campus Academic Mentors or CAMs, assigned to each section and the department professional advisor. Student feedback to these sources indicate that the students enjoyed being able to utilize the senior design fabrication facilities. Overall, the College Success course provided a motivating experience for the students and contributed to their "hands-on" outcomes experience. Student feedback from the course indicates that the focus on use of new facilities should continue and be enhanced even further in the future.

Solid Mechanics

The Solid Mechanics course taught at ERAU is much like solid mechanics taught at any other university with traditional degree programs in civil, mechanical, and aerospace engineering. Students typically take this course in the second semester of their sophomore year, and this course is often regarded as the first course in structural mechanics (this latter point could be argued, depending on how one views a course in Statics). The content of this course has changed surprisingly little over the numerous decades in which it has been taught to aspiring engineers. Most instructors spend a portion of the lecture time teaching theoretical principles of topics such as beam bending, superposition, and buckling, and the remaining time working examples on the board. Student assignments usually consist of additional problems solved with no more than pencil and paper. Most instructors may take students into the laboratory for a quick presentation or two, perhaps involving a tensile test or a demonstration in beam bending, but typically no more than this.

Our Aerospace Engineering program has long attempted to have a strong laboratory component and a “hands-on” approach to engineering education. Additional avenues of improvement in this regard have opened up due to curriculum changes favoring laboratory and design work. However, laboratory content is noticeably lacking in the structures sequence of courses until late in the aerospace program, either during the junior year, or more typically in the senior year,
depending on how students arrange their schedules. Solid Mechanics offers an ideal time in the four year program to introduce the students to structures in the laboratory. Unfortunately, it is currently unlikely that the course can be modified in the near future to include a formal laboratory component. Therefore, informal laboratory content must be added within the confines of a typical three-credit course, which meets three times a week for an hour lecture.

The current instructor for Solid Mechanics made the commitment to add significant informal laboratory content to the three-credit hour course in Solid Mechanics when the AXFAB facility was opened. While significant funding of new equipment was included in the cost of the building, the primary reason for the ability to conduct portions of Solid Mechanics in the facility is the generous floor space in each room, enabling the instructor to have course sections of moderate enrollment (at least 20 students) come into the lab and work around tables and equipment for at least a portion of the one-hour class period. Since the facility is dedicated to undergraduate education, there are no graduate students with large research projects strewn about the lab, which allows large groups of students to have access to most lab spaces during the majority of the academic year.

Current section enrollments for Solid Mechanics are usually 20-30 students, with an occasional small section. A class of 30 students still often demands that the students be split into two groups for a worthwhile laboratory experience, but this is being accomplished with a minimum of planning. In these laboratory exercises, which will eventually occur every week or two, students are required to take data, and later compare experimental results to theoretical results using the techniques taught in lecture.

Students are introduced early to the use of strain gages, and while they are not asked to apply them to the structures to be tested, they will gain experience in reducing data and calculating stresses from strain data. Experiments in the first month include axial loading and tensile testing, including shear loading and failure in fasteners. Beam bending, including axial and shear stresses, and torsion of shafts are demonstrated in the second month. The final month includes beam displacements and buckling behavior. Many of these experiments were constructed and implemented in the Fall 2006 semester, and most of the remaining experiments will be fabricated and implemented in the Spring 2007 semester.

The impact on ABET accreditation will be the acknowledgement of a laboratory component where course content is mapped to specific outcomes. Whereas Solid Mechanics has previously been predominately mapped to Outcome 3 – Engineering Fundamentals, in the future, Outcome 8 – Laboratory and Computer Proficiency can now be linked to Solid Mechanics at the very least with a notation of “Peripheral Attention,” and perhaps with several semesters of success, upgraded to “Significant Attention.”

Engineering Materials Science with Laboratory

The Engineering Materials Science course was until recently a three-credit hour lecture with a zero-credit hour laboratory (meeting once a week for an additional three hours), devised a long time ago with logic and reason that predates the current instructor. Recently, this glaring
inequity (especially so in the eyes of the students) was corrected and the result was a two-credit hour lecture and an accompanying one-credit hour laboratory session (again, resulting in a total of three hours a week). Part of the reason for this change was the addition of the AXFAB facility, and the formal acknowledgement of increased emphasis on substantial undergraduate laboratory content throughout the curriculum.

The Engineering Materials Science course has always emphasized the laboratory component as critical towards achieving the documented ABET Outcomes, especially within the structural mechanics sequence of courses. However, proper facilities were lacking, both in equipment and space. A critical event occurred during one of the regular meetings with the IAB for the AE program, where the board members were given a tour of the old laboratory facilities and asked for an evaluation. It was found that while the department was making the best of the limited facilities, substantial improvements were critical to continued ABET accreditation. Up until the opening of the AXFAB facility in Fall 2006, students enrolled in the Engineering Materials Science Laboratory were split into two groups, and often alternated weeks in which they would conduct particular laboratory assignments because of the cramped conditions.

The instructor used the introduction of the two-credit hour lecture with one-credit hour laboratory, combined with the AXFAB opening, to institute a new series of laboratory experiments in which every student would attend the laboratory session every week, once again further supporting the “hands-on” learning that ERAU has continually emphasized. Separate laboratory spaces for mechanical testing, metallography, and microscopy all serve the Engineering Materials Science course. The old materials laboratory building is now used for composites fabrication, to segregate the “smelly” types of fabrication and assembly. Students now participate in a wide range of testing materials following numerous ASTM (American Society for Testing Materials) standards each semester. Students receive hands-on training on the scanning electron microscope (SEM) with energy dispersive spectrometer (EDS) in an effort to understand failure mechanics and important features of fracture surfaces, in a workspace far removed in concept from the broom closet which served as a microscope room for many years.

It is unlikely that a stronger quantitative mapping of course content to ABET Outcomes will be noted in the next series of ABET documentation, since the program claimed “Primary Attention” to Outcome 8 – Laboratory and Computer Proficiency with the Engineering Materials Science course. However, it was noted that the previous laboratory space was insufficient for continual accreditation. With the addition of the new undergraduate laboratory spaces dedicated to the Engineering Materials Science course, as well as other courses, the program has very strong justification towards continuing to claim an emphasis in “hands-on” learning is subsequent ABET documentation.

**Experimental Space Systems**

The experimental space systems laboratory course is taught in the Space Systems Lab within AXFAB which has two large rolling tables and three large plasma televisions coupled to three of five computers available for students. There is also an air bearing and a vacuum chamber, as well as storage units inside of this lab. Across the hallway through aligned double doors with large windows is the astronautics fabrication room which is a sub-shop connected via garage
type doors to the primary machine shop. Cattycorner to the laboratory room and the machine shop is the classroom in which Experimental Space Systems is taught.

The computers resident in the lab have all of the university-student software from previous classes, including CATIA and Matlab. These computers also have custom software for operating radio equipment installed on the roof of the building which is used when receiving satellite transmissions or bouncing signals off of satellite repeaters. The accounts students log onto in the room are the same individual accounts, including memory, which they have used for all classes over their entire university experience. The air bearing floats student-built satellites on a thin, semi-spherical cushion of air to allow for attitude control simulation. The current vacuum chamber is 30 inches in diameter and 36 inches long and can house the smaller student satellites. A 50 inch diameter 70 inch long chamber is on order and should be in place by the time of publication.

One class objective has been to have depth in theoretical computational and experimental methods. The new facilities have been of great benefit to this by allowing the removal of distance between the lecture room, lab room, computer facilities and machine shop. Students create numerical models of hardware systems they transform into physical models. These models allow them to compare their experimental results with the predicted results using large plasma screens while the experiment is running. This experience allows for increased learning through immediate feedback. Previously, students would have needed to write down experimental results; then compare them against individual predictions. Now, students can modify the implementation of the numerical models ‘on the fly’ to get a best fit and make a prediction of how to improve the experiment based on the latest results as they are coming in. The rapid feedback caused by the numerical model experimental interaction allows for far more time to be spent intentionally optimizing the experiment than was previously available.

One class outcome has been to give students proficiency with modern equipment and current laboratory and computer methods. Again, the new facilities enhance our ability to address this outcome by providing additional space for larger vacuum chambers and an air bearing. Previous student satellites were limited in size to approximately three feet in diameter based on what the machine shops and fabrication rooms could comfortably support. The latest student satellite was eight feet long which is now large enough for planned additions of computer processors, momentum wheels and other student payloads.

A second outcome addressed by the new facilities is the ability for students to demonstrate proficiency in core topics inside of the program. This is facilitated by having sufficient space for students to work more independently and spread out with fewer constraints placed on their satellite designs due to limitations other than their own proficiency.

**Spacecraft Detail Design**

The ERAU Spacecraft Detail Design course is the final of a sequential series of courses leading to graduation in the Astronautical Engineering track in the AE Department. In this track, the student concentrates on a specific spacecraft related subsystem and follows through with the design and building process. This process is closely related to the NASA Program & Project
Life Cycle, which is explained in the NASA Systems Engineering Handbook\(^3\). The preliminary design course precedes this class, but has generally no hardware component. In the preliminary design class the students conceptualize a mission and perform hardware specification and analysis in a simulation environment. The simulation environment using Matlab/Simulink aims to keep the subsystems modular, so that specific subsystems can be tested as ‘hardware in the loop’ components in the detail design class. It is very important to mention that, in the detail design course, the compilation of a requirements document, which is based on the systems specification, must be in line with the test plan, which is executed at the end of the semester. A conformity inspection at the end of the semester determines the students’ grades and completes the course requirements.

In order to comply with the technical deliverables (System Concept & Architecture, System Specification, Interface Requirements, Engineering Tests, Specification Tree, Drawing Tree, Parts and Subassembly Lists, etc.) mentioned in NASA’s System Engineering handbook, a very rigorous Configuration Control structure is applied in this course, including a release process managed by faculty. Each semester a new project number is assigned for the development of the product structure tree and product bill of materials. The students have access to all previous configuration managed and released systems and subsystems. This gives the student an industry-like setting in the final capstone design sequence, which comply with ABET outcomes.\(^2\) The students make extensive use of the new Space Systems Lab and the new Machine Shop. The newly developed hardware is tested and conformity inspected in the Space Systems Lab previously mentioned and may be reused in following semesters.

**Aircraft Detail Design**

The ERAU Aircraft Detail Design course is the second of a two-part capstone sequence during which design teams perform detail design on an aircraft conceptualized in the Aircraft Preliminary Design class. The course requirements include the fabrication and testing of both wind tunnel and structural models representative of a chosen aircraft component. This effort requires students to spend large amounts of time in the Machine Shop, Wind Tunnel, Structures, and Mechanical Testing Labs. Previously, these facilities were all housed in separate buildings, all of which were cramped and stocked with outdated or nonstandard equipment. With the completion of the AXFAB building, three of these facilities are located under one roof, with the Wind Tunnel Lab located in a building which is only steps away.

One of the primary advantages of the new facility is an Aeronautics Fabrication area which is dedicated to the Aircraft Detail Design students, allowing them to work on and store their projects in a spacious area without concern of interference from students in other classes. Light equipment is housed in this area (i.e. a drill press, band saw, belt sander, etc.) allowing students to continue to work on their projects in the evening after the Machine Shop is closed. Storage lockers are also provided allowing design teams to store their projects without fear of other students tampering with them.

Aircraft Detail Design students are also making use of the three dimensional printing capability resident in the Rapid Prototyping area in creating wind tunnel models. Design teams now create CAD assemblies of their wind tunnel models, and download these files to the 3-D printers. The
printers create individual components which are then assembled using steel rods and epoxy, and then sanded and painted to complete the wind tunnel models of their aircraft. Using this method allows teams more time to concentrate on other aspects of their design and still create aircraft models of high fidelity for use in collecting the aerodynamic data necessary to verify their design assumptions.

Another substantial improvement in course instruction occurs when students are able to perform real-time simulation of their structural models as they are being tested. Each design team creates finite element models representative of the structural model they are testing, and the computer facilities resident in the AXFAB Structures Lab allow them to monitor strain and deflection measurements relative to their computer simulation as the test is occurring. This process allows students to perform real-time model verification and make adjustments to their testing sequence by simulating anomalies that occur during the test.

The ABET student outcomes which are most readily impacted by the new facilities are Outcomes 6, 7, and 8. Outcomes 6 and 7 state that students must show proficiency in design and demonstrate design competence through a capstone experience. Outcome 8 states that students must show proficiency in using modern laboratory equipment. The improved facilities allow students to work in a modern environment which is similar to that which would be found in industry. For example, the Structures Lab houses a 150 kip reaction frame that was designed based on input received from structural test engineers working in industry. This timely instruction for graduating seniors is invaluable in allowing them to complete their capstone projects using methods that will translate easily to those used in industry or graduate programs.

**Undergraduate Research**

Student research has also been directly and favorably affected by the new facilities. There are now two dedicated research rooms with computers. The research rooms have large double doors with large viewing windows allowing for greater hardware access and easier instructor monitoring. An example of the research capabilities now available was recently demonstrated when two students constructed a 1600 pound, twenty foot long magnetically levitated linear induction catapult inside one of the research rooms during the first semester the building was available. Having access to CATIA for design work and to the machine shop for manufacturing within the same building as the faculty’s office cut down significantly on time wasted walking between buildings and on time wasted trying to locate other group members.

There are at least five student research projects currently housed inside of the building. Having so many research projects located so closely together allows students to continually work on their projects without violating safety codes which do not allow students to work on projects alone. It allows for a critical mass to assemble because students can have more confidence that they will have access to their projects during unscheduled times. The co-location of projects also allows students belonging to separate teams to assist each other during critical times when additional manpower is needed for short durations (for such tasks as moving large hardware or completing data acquisition phases of experiments).
Conclusion

The previous sections have described several examples of how the new AXFAB facility has enhanced the ability of ERAU instructors to better meet student outcomes as defined by ABET. Of particular emphasis is the capability instructors now possess to mesh theory, computation, and experimentation into their instructional methods. Student feedback has been overwhelmingly positive regarding the curriculum enhancements which have resulted from the increased capability the new amenities bring. There is an underlying tone of excitement which has been added to all design and laboratory based courses that make use of the new facility. The AE faculty also has a high level of confidence that these enhancements will allow our department to further demonstrate ABET compliance during the scheduled 2010 audit.

Several course improvements are planned prior to 2010 which will be geared toward making better use of existing equipment and utilizing supplemental equipment which is planned for procurement within the next few years. Examples of this are an increased number of load actuators to be added to the Structures Lab to allow distributed loads to be applied to test articles fabricated for Aircraft Detail Design through a ‘whiffle tree’ arrangement. Additional load frames are planned for the Mechanical Testing Lab, which will facilitate fatigue testing of coupons to support the Materials Science course and allow the potential for creating new technical elective courses geared toward this type of structural testing and analysis.

Undergraduate research efforts will also be more easily initiated and completed through the use of existing and planned equipment, allowing for increased potential for outside sources of revenue for the University. A clean room is planned for a portion of the research space so that students can assemble experiments in a pristine environment. A ground station and receiving antenna have also been added to the Space Systems Lab and will be used to support space-based research projects.

This coming fall, the "Introduction to Engineering" course will utilize the rapid prototyping facilities in the new building to enhance the first-year design experience. Additional curriculum improvements will be achieved once the faculty gain more experience in using the facility and more fully understand the capability of the new equipment. In the meantime, the improvement in the undergraduate learning environment afforded by this new facility continues to better prepare our students for the next phase of their academic or professional careers, thereby adding to ERAU’s reputation for producing quality engineers who understand the relationship between theory and application.

References

1 Criteria for Accrediting Engineering Programs Effective for Evaluations during the 2003 – 2004 Accreditation Cycle, Engineering Accreditation Commission, November 2002

2 ABET Self-Study Report for the program in Aerospace Engineering, Embry-Riddle Aeronautical University, submitted to the Engineering Accreditation Commission, June 2004