Flexible and Enduring Engineering Education Built on the Basics and Reinforced through Practical Problem Solution

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Abstract

Students in any discipline learn and retain more when exposed to material that stimulates their interest. In engineering, all students must understand certain basics in mathematics, physics, or the concepts of their chosen discipline. A student may be able to memorize or otherwise master an advanced concept without the basic knowledge to verify the technique or result. Theoretical concepts in early undergraduate courses are sometimes difficult to comprehend when a student may not see a direct application of the material to a practical system. Often students are required by instructors to apply a particular software routine or code they do not understand. When this occurs, the student becomes a data-in-data-out technician and ceases to be an innovative engineer who can solve problems. Students must understand the basics before they can understand more complex concepts. There appears to be two compelling reasons why some engineering curriculums are not stressing the basics. First, many years ago the computer explosion made solutions much easier and primary while the basic concepts necessary for the solution method became secondary. The students then believe all knowledge required for the solution of problems is stored in the computer and does not need to be known or understood. Second, the engineering educators became fixed on research and assumed their students wished to pursue advanced degrees. The fallacy of the assumption is most students want to seek employment after graduation and utilize the undergraduate education just received. This paper discusses the above postulates and proposes some solutions and a system of practical courses to stress and utilize the basics for enduring engineering education.

Introduction

Observations of some tenured engineering educators who teach undergraduate design courses indicate a concern over the lack of emphasis on basic knowledge in the engineering curricula. In this document, the authors list some of these issues for consideration in undergraduate programs. Apparently, some prerequisite courses in engineering disciplines emphasize the theoretical approach without proper basic knowledge or practical reinforcement. It is often assumed students thoroughly understand mathematics, physics, and basic discipline specific knowledge before advanced theoretical techniques are introduced. Students can master advanced techniques without understanding the basic principles or limitations of these concepts. In many design courses throughout academia, students are given previously developed routines or programs to utilize in problem solution. Even in industry/academic cooperative programs, students are instructed to use computer routines that merely accept and return numbers. These programs do not encourage initiative or innovation and are usually not motivational to the student. If students do not understand how or why these computer aides calculate results, the bounding conditions cannot be justified and the output cannot be verified. When asked, the student may reply, “I don’t need to understand how to accomplish a task, I can just google it”. In this case all the intelligence is in the box under the desk and the computer on the student’s shoulders is not designing the object. This seems to be more prevalent with the explosion in our technology and communications. Advances in our technological tools are incredibly useful but we must heed a caution by a very intelligent individual named Albert Einstein when he is reported to have said, ”I fear the day that technology will surpass our human interaction. The world will have a generation of idiots”.

Advancements in technology have allowed tasks that once took days or weeks to be accomplished now can be completed in minutes. These time saving computer methods open up a vast new world of nearly infinite possibilities that are accompanied by some often overlooked consequences. If these drawbacks are not considered and addressed, the human interaction and reasoning capability may be lost. Young engineers fresh from a higher education program that does not stress the basics may be able to generate solutions using purely theoretical or computational techniques but lack the practical knowledge to determine the validity of a result or to modify an existing solution method to meet the parameters of a different environment. Using the time-saving computational techniques not only encourages students to dismiss a need to learn and retain but also stimulates faculty to lose focus on teaching basics and focus on researching and applying advanced techniques in the classroom before the students have the capacity to absorb these concepts. It seems most faculty now are focused on preparing the students for advanced education on a masters or doctorate level instead of preparing then to be successful as a freshman engineer in the industry. Many of our universities have lost focus on educating the undergraduate students and focus only on the graduate student who contributes more to faculty gratification and institutional prestige which is rewarded with grants and funds. The undergraduate students are taught by the teaching assistant graduate students while the faculty are working with the graduate level students to publish. Knowledge discovery is wonderful and necessary at an institution of higher learning, but only effective when in balance with teaching practices that prepare a student for lifelong learning whether in a laboratory or on the assembly line floor.

The purpose of the examples and proposed solutions that follow in this paper is to draw attention to changes in our engineering pedagogy that have occurred over the last few years and to encourage a re-focus that may positively affect our undergraduate engineering education. This paper describes some changes in aerospace engineering that have both positive contributions and negative consequences. There are also similar examples and solutions in every other engineering disciplines. Students learn and retain much better when the basics are understood before advanced concepts are introduced, and when practical applications reinforce technical concepts. In the following text, examples of problems created in aerospace engineering are illustrated and some solutions offered. Also, a three course sequence of aerospace engineering courses stressing practical, team-based courses is explained.

Aerospace Engineering Evolution Problems and Practical Solutions

The use of high powered computing has caused a diminished emphasis on understanding the fundamentals. An example is the focus on the power of computational analysis and the de-emphasizing of experimental verification utilizing wind tunnels. When the computer explosion occurred over 30 years ago, the computational capability was assumed to be so powerful that code verification from other sources was unnecessary and a devastation our wind tunnel facilities began. Many NASA, military, and private wind tunnel facilities were shut down and dismantled because the assumed computational fluid dynamics (CFD) capabilities made these physical facilities seem obsolete. It took many years to finally realize other sources of verification were still necessary to reduce the risk of making a bad decision based on one source of information. It is also documented in recognized reference texts like *Theory of Wing Sections*[1] that the accuracy of theoretical predictions was not nearly as great as anticipated. In fact, the 80 to 90 percent solution using theoretical techniques was extremely optimistic. Because of limitations on theoretical analysis, wind tunnel facilities are currently re-opening and in some cases building new facilities for experimental testing and verification. Many industry organizations (nearly every week a request goes out asking about wind tunnel time for industry applications) are now seeking testing facilities to verify theoretical results. Often, engineering faculty have led the students to believe the theoretical solution is the only valid method when others are available and are actually essential to process the best solution. Sometimes, the students are instructed to use codes they do not understand simply because the faculty member uses these codes in their research. Ultimately, the student learning and motivation goes down. To attain the best solution to a design or modification problem, all available verification methods must be employed. Therefore, a combined method of practically applied basic principles, theoretical predictions, experimental verification, and flight testing will result in the most effective solution.

Another example of ignoring the basics for the theoretical is illustrated by the course curriculum. The computer explosion emphasized theoretical concepts and most curriculum developers added these techniques while maintaining the existing practical courses. When apparently there was not sufficient time for both approaches, the computer-driven theoretical approach prevailed in most university curricula at the expense of the once popular practical approach. One of the authors of this paper was teaching the Aerodynamics I course from a practical text used at two exclusively undergraduate institutions, Embry-Riddle Aeronautical University (ERAU) and the United States Air Force Academy (USAFA). Some faculty who advocate the undergraduate institutions be exactly like the research and publish graduate schools, supported changing to an essentually theoretical, potential flow theory text. The instructor complied and used both texts which effectively nearly doubled the student workload. The increased workload actually decreased some learning objectives but stimulated interest and motivation with the students. However, the author saw other instructors of the course succumb to the pressure to implement the theoretical text and approach to education in aerodynamics. A few semesters later, this author had some of the students from the entirely theoretical aerodynamics course in the capstone design course. It was apparent early in the capstone course the students did not possess the practical knowledge of aerodynamics to be successful in the performance-driven, aircraft design course. The author implemented practical aerodynamics and aircraft performance in the design course to fill the gaps in student understanding created by the purely theoretical approach to aerodynamics. This lack of practical knowledge stimulated the author to develop a prerequisite course in aircraft flight mechanics and performance to aide student success in aircraft design. Now the capstone aircraft design courses have been modified to accommodate practical design and wind tunnel testing methodology to develop the best solution.

In the first new course mentioned above (Aircraft Flight Mechanics and Performance), lecture and research techniques are utilized in aerodynamics, aircraft performance, and static aircraft stability to analyze the performance characteristics of a student-selected, existing aircraft. The course lectures contain references from many authors/texts for researching and understanding various techniques to analyze aircraft characteristics. Students apply the various techniques in groups of three in the five assigned projects. The projects also enhance communication skills by requiring five written reports and a final presentation. An outstanding motivational aspect of the course is the students compare results to published results of existing aircraft. In the second course (Aircraft Preliminary Design), student groups of 6 to 9 (Integrated Product Teams, IPTs) are given only performance parameters for a given type of aircraft and the IPT completely designs the prototype, capstone-course aircraft. Results are documented in four presentations and three reports. The final presentation is evaluated by a panel of industry experts who assign a grade for the students and valuable industry perspectives for the students and faculty. In the third course (Aircraft Detail Design), the same design groups continue the capstone experience by taking their aircraft into the next phase of the Research, Development, Test, and Evaluation (RDT&E) process by applying wind tunnel testing, model modification, and re-testing to verify the best design solution. The IPT will complete the project by making a configuration recommendation for the first flight test aircraft to the panel of industry experts. Assessment of the value of this basic knowledge, research, and problem solution technique is measured by the panel of industry representatives who evaluate the final presentations. These documented evaluations show improvement in student success, knowledge retention, and preparation for the freshman engineering job.

The dramatic increase in computational capability (higher speeds, higher densities, better codes, better interfaces, etc.) that started in the 1960s and 1970s spurred a revolution in computational methods. Despite the vast improvements in engineering capability that evolved from this revolution, engineers have failed to solve some basic pedagogical challenges in engineering education caused by this revolution. Several crucial battles have already been lost, and some of the trends may be irreversible. One issue is regarding the topical content and quantity of content in an engineering degree program. Apart from the extra training in math and computer programming required for teaching computational methods, a whole new discipline of grid-making (or meshing) came into being. Furthermore, classical engineering principles had to be extended to computational methods. This was easily more than a year's worth of extra content being added to an already rigorous and challenging degree program. Engineering educators were concerned that our most talented and promising students might opt for the less-demanding 4-year programs in other disciplines. Instead of devising a rational length for the engineering program, this additional material was simply inserted into a four-year, grueling, mind-numbing experience. Then unmanageable programs began systematically cutting out the classical / practical / applied material to make room for the computational addition. A solution to the sometimes overdemanding, short engineering program is to maintain the classical approach, introduce some computational theory in the undergraduate curriculum, move some of the computational to graduate curricula, and offer an extended program which could provide depth in some areas of interest to the students.

Another area of concern in aerospace engineering is in an identity crisis. Some engineering programs are deliberately evolving away from ***engineering*** programs toward ***engineering sciences*** programs and in some cases, the transition is virtually compete. The former programs prepare undergraduates to get entry-level jobs as engineers in careers in government or industry. The latter programs screen students to serve initially as low-paid workers in funded research programs and then eventually to earn doctorates for careers in research in academia. As a result, engineering programs have gradually been re-populated with research Ph.Ds. instead of journeymen engineers, and the apprenticeship model of teaching engineering has been replaced with a pedagogical model. We hire and reward professors for writing research grants rather than for stimulating innovation in the students or creating collaboration with engineering activity in industry. Due to lack of experience in industry, what is taught in the curriculum is often not placed into the context of the engineering risk reduction process. Consider how many of the great aircraft designers of the past century -- American or otherwise -- had a Ph.D. The answer, of course, is none. How many of these, regardless of their success in industry, could get a job teaching aircraft design at a “research university” in America today? The answer is, again, none. They don’t have the publications or funded research programs to even get an interview. Many times students ask the faculty what does it take to be successful in the industry environment and the faculty have no reply because there is no experience. The most obvious solution to this problem is more diversity in hiring faculty. Certainly there is a need for credentials in an engineering curriculum, but there is also a need to help guide the students by educating them in the environment they will face upon graduation.

Another concern in aerospace engineering is the engineering co-op program, which provides entry-level experience in industry and partially replicates the classical apprenticeship model of engineering education. Many research professors who want to reduce the number of courses they teach or the number of exams they have to grade are seeking more depth rather than breadth for their students. Even though the apprenticeship model helped produce the generations of American engineers who put men on the moon and created vehicles that fly at hypersonic speeds, research professors in general have no interest in sustaining a co-op program and are usually content to let it decline. Our industry is encouraging co-op experiences to the extent one major company has indicated that in the next five years, no student will be hired from an engineering undergraduate program without co-op experience. So, undergraduate programs must emphasis co-op programs and find innovative ways to schedule these into the curriculum.

A final concern for the aerospace engineering curriculum involves appearances of misuse of the undergrad capstone aircraft design course. Engineers know capstone is essential preparation for that first job in the real world, since it may be one of the few opportunities, if not the only opportunity, an undergrad will have to integrate what they’ve learned in their coursework in the context of the whole system and to realistically exercise multi-disciplinary synthesis, leadership and teamwork on large projects. In many cases, however, the capstone aircraft design course has become a dumping ground for requirements not met in other courses. In other cases, students have not been given adequate skills. These skills must then be taught in the design course in some kind of crash-course, lick-and-a-promise fashion that is neither sufficient nor efficient. Time supposedly spent integrating and exercising skills supposedly learned in previous courses is instead spent introducing new skills, which in turn takes away from time required to replicate the iterative nature of the design process. It also significantly drives up the workload in the course, which diminishes the enthusiasm and participation in what should be the most fun course in the entire curriculum. Researchers also see no place in the curriculum for the capstone engineering design course, which functions as an exercise in engineering creativity, engineering risk reduction, and integration of a broad range of engineering sub-disciplines and skills. Engineering design is also conducted at higher technology readiness levels than those seen in research. In many researchers' minds, the time would be better spent enhancing depth of content in a sub-discipline as preparation for graduate research. If it weren't for the professional engineering societies and the agencies that accredit college degrees, the design courses might also have gone the way of the co-op program. Nonetheless, even those who aspire to get a Ph.D. and do research need to understand engineering design and the whole airplane (or other system) as the context for their research. The demand for properly-engineered products is what drives the demand for research. If you don't understand how your research makes the airplane or other system more economically or operationally effective, you can't know if your research is doing any real good and you won't be able to effectively justify your requests for funding. Many researchers would also benefit from the reality check provided by a job out in the real world. A solution may be, as before, the diversity of hiring faculty. Hire some who have the credentials and desire to accomplish research and hire some who have the experience to help prepare the students to be successful in the industry they have chosen.

Summary and Recommendations

The aerospace engineering industry has, over the last few years, emphasized basic, practical engineering education. The co-op programs have increased and hiring from these programs has doubled if not tripled. All of our Industrial Advisory Board members and other industry representatives have complemented the practical, project based education in our curriculum. It is evidenced in the hiring rates for our graduates in the first year after graduation. Although we have no data from other schools, we are told our percentages of graduates who are working in the aerospace profession in their first year after graduation is very high due to our focus on undergraduate education and the graduate's practical application skills.

Ignoring some of the challenges listed in this document and taking the easy way out only guarantees the law of unintended consequences would be enforced with devastating effect. Inserting five years of content into a four year program only served to aggravate the attrition out of engineering and into other, less-demanding degree programs. The fear that we'd lose our talent was fully justified by trends in declining enrollments in engineering. The same justification was also used to get rid of the highly-successful co-op programs, which was an attempt to recover some of the features of the apprenticeship model of teaching engineering. Our

students now lack intuition that comes from the classical / practical / applied material, and they have no intuitive basis to evaluate what comes out of the computational techniques.
The computational pioneers eagerly over-sold their capabilities, and decision-makers were ready to believe promises about wind tunnels being obsolete and ready to be replaced by cheaper computational methods. Lacking understanding of the limitations of computational methods, having oversold the capability of those methods, and having failed to understand the place of classical / theoretical methods, computational methods, and experimental methods in a multi-phase engineering risk reduction process, we've allowed our experimental capability to atrophy. Wind tunnel capability has eroded to the point that it may not be recoverable. And, we must insist that computational methods be validated against experimental results before they're employed to extrapolate results for new designs.

Some may argue that the ideal is to strike a balance between graduate research in engineering science and undergraduate engineering. A similar argument is that research enhances undergraduate education. Both are true to some extent, but the reality is that graduate research programs tend to grow and absorb disproportionate fractions of funding and faculty attention while undergraduate programs atrophy unless the engineering school deliberately maintains its identity as an engineering program rather than an engineering sciences program.

There are some questions the engineering education community should be asking over the next few years:

1. Do we have the desire to regain our identity and serve our industry customer?
2. Who are we? Scientists or engineers? Graduate programs or undergraduate? What's our first priority?
3. Can we properly structure a curriculum and a faculty and an academic environment that makes sense for undergrad engineering students and the rookie engineers they're about to become?
4. Can we recruit and motivate and incentivize the right students? Can we fix the pipeline?
5. Can we teach the engineering profession or do we just teach technical topics?

Bibliography

1. *Theory of Wing Sections,* Abbot and Van Dornhoff.
2. Embry-Riddle Aeronautical University, *Survey Report, Cap and Gown Fall 2014 Results,* Prescott Campus, Office of Institutional Research.