THE COMPREHENSION CHALLENGE

The need for increased attention to depth of comprehension in US engineering education is being recognized once again. In a dawning era of automated open courseware and mass commoditization of engineering education, the competitive edge will go to those who can instill depth of learning. Our EXTROVERT cross-disciplinary learning system enables the best of our students to achieve substantial new capabilities that are showing impressive results. Insisting on depth in courses is becoming more risky,..

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Abstract

The need for increased attention to depth of comprehension in US engineering education is being recognized once again. In a dawning era of automated open courseware and mass commoditization of engineering education, the competitive edge will go to those who can instill depth of learning. The EXTROVERT cross-disciplinary learning system that has been developed at Georgia Tech enables the best of our students to achieve substantial new capabilities that are showing impressive results. Insisting on depth in courses is becoming more risky, due to a combination of student attitudes and lack of interest in logic and derivations, and administrative apathy and pressure that drive standards down..

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Introduction

Renewed emphasis on the depth of learning has become crucial in the fast-evolving environment of engineering education. The paper briefly considers why this is needed whether one desires breadth or depth, summarizes efforts by our team to construct, test and use resources that facilitate learning and problem-solving across disciplines. We describe how these multidisciplinary resources serve the purpose of enhancing depth of comprehension, as well as confidence and capability to solve problems that require breadth. The thrust of this paper may be summarized as follows:

- Graduates must know and be able to use what they are supposed to have learned.
- There is a large opportunity for improvement in depth of learning.
- Technology can help by providing access to in-depth knowledge resources.
- Demanding depth is controversial and encounters stiff opposition.
- Learners' efforts vindicate our efforts

The massive effort to reform undergraduate engineering education over the past 20 years has generally emphasized breadth and soft skills, inevitably at the expense of quality and depth of learning in core subjects. One easy metric is that while the number of credit hours needed for graduation has gone down, typically by about 8%, a number of "softer" subjects has been introduced, at the expense of hours devoted to core depth. Thus the core courses have been compressed heavily, while no compression effort is evident in the "soft" courses. This compression certainly came at least in part from removing items that took too long to teach or learn. A detailed presentation of those statistics is beyond the scope of this paper but is surely evident to experienced teachers.

Studies did indicate that core depth was important. For instance, Evans et al [1] found that all three of their customer groups (alumni, students, faculty) rated "problem recognition and solution" as the top desired attribute. Unfortunately, breadth and depth in the subject discipline were lumped into one attribute and so depth appears to have generated no attention. Bordogna[2] emphasized integration for innovation, exhorting educators to show students the engineering purposefulness of the whole enterprise. Although the need for a knowledge base and the intellectual capacity for lifelong learning were emphasized, the need for depth was countered by the idea that the 4-year undergraduate experience should be to develop students as emerging professionals rather than fully trained engineers, and that the student should be a satisfied customer of the process, making the study of engineering more attractive, exciting and fulfilling throughout". They argued for a shift in emphasis from "dedication to course content" to "a more comprehensive view, focusing on the development of human resources the broader educational experience in which the individual parts are connected and integrated". Olsen and Hucklin[3] argued that "students should be taught how to listen to lectures in a more rhetorical, strategic way. More generally, if we are to teach students to understand and communicate more effectively, we should help them see how the organization of their discourse fits into the larger goals, agendas, and contexts in their fields." Somewhere in the course of heated argument, the legitimate notion that college should educate for a lifetime, rather than train for the first year of employment, appears to have been replaced with an absurd outcome: pressure demanding to fill the time available to learn engineering, with many other things. Thus in the last two decades, numerous changes have been instituted in engineering curricula, and the pendulum has swung heavily towards the prescriptions indicated above.

Concern about depth is evident in several fields, and lessons on this from previous eras are still relevant. Pyle [4] expresses concern about the declining mathematics ability of engineering college entrants in Britain, set against the key role of mathematics in engineering. Here again it was assumed that engineering schools would not compromise on mathematics requirements – an assumption that does not hold up when viewed against the requirements for some engineering degrees. The indispensable value of depth in education is becoming clearer as the developed nations face tough economic times, with worldwide competition based on quality and price of products. McKeag[5] sees improved engineering graduates as the saviors who can improve competitiveness and thus help lift Britain out of the economic downturn. They point to published evidence that "deep immersion is required in a discipline before anything of novelty can be produced. All evidence indicates that real competence only comes through extensive practice". They also point out a "tendency to cut out substance from subjects to the extent that students end up dumbed down without the tools to be creative". They point to the accepted 5 techniques as sources of new ideas: adoption, technology transfer, combination of multiple ideas, analogy, and chance, and then point out that "chance" favors the prepared mind, so that "deep immersion and deep understanding in a discipline are required before anything of novelty and value is likely to emerge". Their prescription is a clear emphasis on the fundamentals of mathematics and engineering science, accompanied by laboratory and workshop experiences. The formative years should be devoted to individual learning, followed by team activities and peer group interactions, and then immersion in creativity and innovation in the workplace, e.g. research participation.

Some global trends are evident in engineering education over the past two decades:

1. Global adoption [6,7,8,9] of the ABET2000 model of self-assessment processes as the basis for accreditation of undergraduate programs, where showing "improvement" replaces standards.

2. Uncritical adoption of the US K-12 model of teaching assessment[10] , exclusively based on the single question on student opinion of instructor effectiveness [11].

3. Emphasis on humanities, social sciences, and "soft skills" [12] in engineering curricula.

4. Emphasis on retention statistics in ranking [13,14] engineering programs.

5. Emphasis on the use of electronic media technology [15, 16, 17] to increase the audience appeal of courses in order to retain student attention and increase student retention.
6. Pressure[18,19] to reduce the time and number of credit hours needed for the first degree
7. The global boom and bust in self-financing, for-profit colleges based on student fee models[20] .
8. The feasibility of delivering engineering education through massive open on-line courses[21] .

Without sustained intervention, the first seven of these all have the net effect of de-emphasizing the use of mathematics, and the depth of learning in core engineering subjects. They amplify each other's effect in deviating from the idea that engineering students must actually learn engineering in engineering school. The last item on the list, the advent of open courseware approaches to reach unlimited numbers of students from a single source, creates a destabilizing effect that has the potential to bring back an emphasis on depth, but that is for another paper to analyze. This paper describes our experience indicating how to facilitate an increasing emphasis on depth.

Ominous indicators of the need for depth

Evidence abounds of the lack of comprehension that comes to the surface when students in upper division courses are asked to deal with mathematical logic and derivations.
1. In our experience, tracing a continuous institutional memory over the past 27 years and over 2600 students, there has been a drastic increase in the percentage of students who will simply leave all questions blank where derivations are sought, even when those are straight from notes and homework. Of those who do derivations, a significant fraction will simply jump across several steps of logic and miraculously arrive at the (known) final result. This appears to stem from their experiences in high school and college, where they learn to look for a final "formula" to "plug in numbers" as the sum

total of their expectation of engineering work. Lacking serious competition nor challenge to obtain stellar grades compared to most of their classmates, these students who become star test-takers are quite shocked to be asked to think beyond memorization. Part of the issue here is that students use electronic devices such as notepads to jot down notes. Equations with Greek letters are more difficult to jot down, and they simply gloss over these.

2. On PhD qualifying examinations, some of the top achievers from many US (and some other) undergraduate programs stumble on basic concepts, and cannot get beyond. Again it appears that they have not learned to think about the physics of the problem, or have no basis for doing so despite all the courses in which they have excelled.

3. On a much grander scale, we have seen instances where the debate on serious global issues descends into noise because some of the protagonists either refuse to or do not have the ability to understand the basic technical/scientific issues. This is again because at the first sight of an equation and a derivation (from first year college physics) they simply turn off their attention.

4. In dealing with undergraduate research students from other universities, it becomes quickly evident that they are lost when they have to find knowledge on their chosen research topic, and unable to use guidance that requires them to use high school mathematics and science. Note that it is harder to gauge this in our own students because they are not given the option of not going back and learning what is needed.

Our observations on opportunities

1. While the media focus has been on the breadth and reach of open courseware offerings, there are other implications. The best institutions, teachers and students will treat this capability as the baseline, and build on it to greater capabilities. These new capabilities will include that of venturing across disciplines, and daring to innovate.

2. Both of these endeavors (excursions across disciplines and daring to innovate) will require understanding technology and gaining physical insight to a greater degree, so that learners can acquire the perspective needed to solve problems quickly in new

areas. The need for this depth will become evident to learners as they actually try using knowledge resources to innovate, and encounter difficulties that require depth of understanding. This is evident from observing the efforts of students and amateur inventors attempting to develop their ideas.

Our Approach

The EXTROVERT project at our institution has been building and testing the resources and learning methods needed to reach these new levels of capability. As this project closes out its 4-year resource-building stage, we are reporting on its status and its continued usage. A core of technical knowledge streams has been installed and is in use. Students are using the resources to solve problems ranging across disciplines. They are learning that they can indeed tackle substantial problems where the level of uncertainty appeared prohibitive in the past. Now they are able to exercise systematic methods to reduce uncertainty and develop viable solutions in areas where they would not have ventured before.

Our approach is to introduce three capabilities into engineering education. The first is a capability to iterate on concepts and skills, and achieve the multipliers in learning that come with experience, within the constraints of linear, sequential curricula organizations. The second, that enables and builds on the first, is the capability to revisit the material contained in courses already taken, as well as preview other course material not yet taken. The third is to exercise the habit of learning in new areas through interactive assignments of substantial breadth and depth. The paper describes the evolution of our strategies for iterative learning within the constraints of an existing curriculum, data from course and undergraduate project experience obtained over a thirty-year period, and systematic assessment results over the past three years as part of an intensive project to build and use resources that help aerospace engineers learn to innovate across disciplines. Experience from several courses across subdisciplines and levels, and from undergraduate projects is summarized on how engineering students learn using different resources.

Some of the key resources implemented are summarized below. A more detailed description has been presented at the last ASEE conference[22].

1. A design-centered portal to aerospace engineering, used since 1997[23] .

2. Vertical streams of technical content, that now enable learners to traverse the knowledge base both horizontally and vertically in several aerospace disciplines [24].

3. A set of in-depth engineering case studies of historically significant vehicle systems, including the capability to compute and check the decisions made by designers[25] .

4. A library of solved problems.

5. Integrative concept essays on various topics.

6. Compact e-books for several subjects.

7. Advanced concept development projects.

8. Undergraduate research testbeds, project documents and papers.

9. A module-based assessment approach to measure learning in near real time to provide feedback and modification during the learning process. Assessment has been conducted across a spectrum of courses[26] .

Changes enabled in courses by EXTROVERT resources

Several powerful capabilities have become available in our classes ranging from a freshman engineering introductory course to upper level and graduate courses, where EXTROVERT resources are added to the traditional textbook, markerboard and classroom. These include:

1. Fast perspective review of related and previous course results at the start of each course, referring students to detailed online notes and examples to refresh and catch up as needed.

2. A "sense of numbers" assignment involving conceptual design, drawing on the experience and access to the Design-Centered Introduction to Aerospace Engineering.

3. Faster coverage of material without loss of comprehension. Instructor spends most of the time in class facing the class rather than copying notes on to the board, since the notes are projected on a screen in sufficient detail. Writing on the board is now reserved to bring forth underlying concepts and work some numbers with student participation.

4. Completion of lecture material well ahead of the end of the semester, permitting extensive revisiting of concepts and contents using assignments and in-class problem solving.

5. Participation credit for students, using a "scratch sheet" given out at the start of several classes, where students write their working and solution of problems that are worked out in class. They bring the sheets to the next class after completing the work, with the "grading" of these sheets done mainly to gauge understanding, participation and attendance. This is to overcome the extreme shyness bordering on trauma of recent undergraduates, when asked to come and participate by solving problems with the instructor's help on the board. Informal discussions indicate that their exclusive dependence on electronic gadgets has actually aggravated rather than evaporated their shyness about speaking out in class!

6. Larger and much more ambitious assignments spanning half a semester or more, where students can work in small teams and across teams with instructor supervision.

7. Bonus points (up to 20 percent) on most tests and assignment, to reward excellence. This recognizes the reality that many of our students are capable of performing at truly amazing levels, far beyond what we as instructors might consider to be "reasonable" on the tests that we set. At the same time, there is a huge spread in motivation and preparation levels, with a distressingly large number refusing to make the needed effort.

8. Assignments where students must explore far outside what is covered in each course, including venturing into resource areas where we have not introduced any material.

9. Multi-week assignments requiring innovation and conceptual design to set the context for engineering science work. In other words, the numbers are not conveniently given to allow formula substitution, but students have to think about magnitudes, find

validating information and techniques to reduce uncertainty, and have a choice of methods.

10. Usage of course material in the context of research projects and developing technical papers

11. Long-term projects involving successive teams of undergraduates without loss of continuity.

Example Use in Problem-solving

Students are using the resources to solve problems ranging across disciplines. With the notes and example problems from previous courses, and indeed of courses in other disciplines not yet taken, students are able to find essential concepts and methods and bring them to bear on problems, both in class assignments and in research projects. The resistance to venturing beyond the notes for the given class, is easily overcome in the case of about half of the student body. Examples are seen in prior papers describing work done by freshmen in conceptual design assignments, sophomores in dealing with the design of aerostats, sophomores assigned to learn how to use examples given at the Wolfram Computable Document Format project website, juniors in major assignments dealing with supersonic transport aircraft[27, 28] and with an aerodynamic Missile Defense System, and research students in various problems such as analyzing a wind tunnel fan[29] , finding high-temperature materials[30] , and developing testbeds for vertical axis wind turbines[31,32] and thermoelectric integrated power generator/ combustor devices[33] .

Dealing with Uncertainty

Students are learning that they can indeed tackle substantial problems where the level of uncertainty appeared prohibitive in the past.

An excellent demonstration of this occurred in a core course setting in the high speed aerodynamics course, where students dealt with a 6-week assignment to conceptualize, size and analyze the aerodynamics of a 3-vehicle system to form a missile defense architecture for the continental United States. Students were given an e-Book description of the nuclear missile standoff and Strategic Deterrence in the Cold War (which ended before the present generation of students were in kindergarten). They had to develop something from nothing, without much precedent, and show that it would work. Despite grave misgivings, the students expressed delight when they found that they did indeed have the background to deal with such a problem, and could reduce the uncertainty to manageable levels, by logic and systematic approach.

Now they are able to exercise systematic methods to reduce uncertainty and develop viable solutions in areas where they would not have ventured before. An example was where a student team was asked to reduce the uncertainty in using 6-degree of freedom load cells for wind tunnel measurements. They came up with better calibration matrices and matrix inversion methods from the published literature, and applied these. They decided to use piecewise linear calibration techniques, and then generated continuous functions by fitting empirical function fits to the coefficients of the matrix defining the interactions between components. They applied this to a problem where the drag of a tree model had to be measured in a low speed wind tunnel, and showed that they were getting reasonable results by comparing to published results using their own component-wise drag coefficient estimates.

Another example of innovation came where a student team was attempting to develop an inexpensive thermoelectric generator for use in kitchen fires to drive air flow and provide steady illumination. They found a mass-produced computer-chip cooling module which provided the needed radiator and heat removal system.

Obstacles

The extensive experience that has been accumulated, also includes collisions with the various obstacles to good learning that are found in the higher education environment. These include, in summary:

Faculty conservatism

The culture of reviewing past work before undertaking a project is no doubt well-ingrained in researchers, but is often not transferred to course preparation. Many instructors still go by their own experience as students in preparing to teach, and many sadly do not bother to observe what others have shown in their own school, let alone in the education literature. This is a severe obstacle to building on accomplished results. For example, let us imagine that a certain body of knowledge and skills was shown to be successfully absorbed by most students taking a certain low-level course. Following instructors could assume that most if not all students who came to the junior level had this capability in their repertoire. However, this gain is lost if new teachers completely ignore its need. This causes severe stress in the upper-division classes, as the gains in standards have to be either given back, or students face a steeper learning curve. Instructors might continue to blame the curriculum for this situation, where a viable solution had been demonstrated. How could such a situation be remedied? No practical alternative comes to mind, other than having thoughtful and proactive leadership.

Administrator ignorance and apathy

In the above hypothetical situation, the solution would be that the administration should continue to retain and insist (in the face of pressures for expediency) on a wise decision from several years ago: that the instructor in the lowest-division courses must be chosen carefully from senior faculty, and must in turn consider the history of how that course evolved. Sadly, the reality is that many administrators have minimal regard for any effort put into ensuring learning, and less awareness of what happens in an engineering classroom. The very strong message conveyed by apathy at this level is that this is all unimportant since it was not done where they got their education in caves in an age when dinosaurs roamed the hot Earth. In the above we show why the need for depth is imperative, and how students are indeed able to innovate with excellent results when we insist on depth and analytical rigor. However, instituting changes in courses that require thinking and initiative from the students, triggers hostile reactions from several who expect to be given everything. Anecdotal examples abound, of students lodging blatantly false complaints, and administrators not taking the trouble to actually figure out if there is any basis for the complaint, but instead seeking to "smooth things over", in other words by pressuring instructors. The excuse given is that they have hundreds of complaints to deal with every semester, so they are too busy to investigate. The obvious implication that the number of complaints may be attributed to the lazy culture of not investigating, is lost on these worthies.

Excessive focus on retention over value

Many of the obstacles come from the excessive focus on student retention and happiness, over value enhancement in college. This can be traced to the nature of performance metrics and resultant pressure imposed on administrators. Ranking criteria in US News and World Report, for instance, do not appear to include value addition in courses, but certainly include student retention numbers.

Discussion

Aerospace engineering has always demanded innovation far into the unknown. Engineers are expected to venture well beyond what is given in their textbooks and handbooks, inventing new fields of endeavor in the process. With explosive growth in technology, the demands on the engineering learner (and all aerospace engineers are learners) have grown beyond the capability of traditional curricula and training programs. Since the end of the Cold War, the industry has flattened into lateral expansion in many ways, compared to the concentration in a few large and stable organizations. At the same time, new concepts require immense Systems of Systems approaches, posing tough challenges to anyone seeking perspective and depth at the same time. The EXTROVERT project considers how to create a learning environment that helps students and alumni to perform such innovation in the midst of the explosive growth in technology. Well-known concepts such as experiential learning and teamwork are recognized, but they are not sufficient to address the immense demands of depth and breadth placed upon the modern innovator. The central finding is that learners can achieve strong gains in depth without sacrificing, and indeed while expanding, breadth of knowledge. The numerous pressures that serve to compress the already dense curriculum, the rising cost of formal schooling, and the fact that our students still come in as teenagers, all must be taken into account. The challenges, background, approach, results and lessons from this project are subject of this paper, done in the final year of the project.

The perspective needed for innovations comes from far-away disciplines (breadth) but is applied to solve intricate problems in a core discipline (depth). At the same time, a harsh reality has to be faced. Most of us do not learn more than 30 percent under the most optimistic estimates, of what we really should learn from the deeper courses in engineering school. Though we may get A grades or 100 percent on tests, this does not imply anywhere such a percentage in actual comprehension and usability of the learning. Those gains come much later in life, with many years of hard experience. Thus the huge opportunity in engineering education is in increasing this level of initial comprehension and competence. We believe that intelligent application of technology with due recognition of both the potential and the limitations of human learners in the

18-26 year age group, offers the potential to make major gains in comprehension. This is the key postulate in our project. A corollary is that major gains in depth of understanding can indeed be used as the foundation of firm knowledge, on which to build a large base of cross-disciplinary information, enabling swift horizontal and vertical transfer and resulting in innovations.

Meanwhile, the reaction of the best students is extremely positive, as their work demonstrates capabilities beyond our expectations based on when we were students, or even as teachers over the decades. A set of well-written letters from these students also indicates their understandable and extreme distress that the environment is failing to stop people who have not gained any significant knowledge or skills to obtain the same degree as those who work hard, and that this is not only tolerated in many classes, but leads to grading practices that completely discourage enthusiasm and effort.

A small footnote is the reaction to draft versions of this paper submitted to the ASEE. Other reviewers who read the paper carefully and made many valued suggestions, agreed that many if not all of the issues cited here rang true in their experience as well. However, one reviewer was quite adamant, demanding that the "author should not be allowed to.." (write obvious statements that made said reviewer uncomfortable) despite it being clearly pointed out that the system of peer review requires a disagreeing reviewer to cite specific facts that disproved the author's assertions and prove them, not just throw tantrums obstructing paper acceptance. This is the classic Immunity to Factual Reasoning Syndome (IFRS) that too many university administrators and wannabes today exhibit with impunity when they get any power at all over others. A clear reference is provided as the reviewer wished[34].

Some Metrics

With the developments that have gone into the EXTROVERT system, some facts can be used to gauge effectiveness:

1. Usage of Case-based assignments has now become routine in Vehicle Performance classes at both undergraduate and graduate levels.
2. The fluid dynamics/ aerodynamics/ gas dynamics curricular stream has become fully integrated, from the Introduction to Aerospace Engineering course all the way to graduate level Advanced Aerodynamics.
3. New ways of teaching advanced courses have become possible. For instance, an Advanced Fluid Dynamics course in Fall 2012 took first-semester graduate students to where they could read, analyze and summarize advanced research papers on a variety of topics, many of which are not covered in the curriculum. This demonstrates the change in culture where students are willing and motivated to do such cross-disciplinary exploration in depth. In Spring 2013, the way we teach Advanced Aerodynamics was completely changed, to one where students could range freely up and down the entire curriculum, and see the commonality in approaches across speed regimes, rather than study individual speed regimes in isolation. The key to this new capability is that students are able to do in-depth derivations and relate them to work done in other disciplines, providing strong evidence that a focus on depth does not have to come at the expense of breadth, in fact the opposite is true.
4. An eBook summarizing the essence of System Dynamics was developed by one of our undergraduates, and has been added to the library of resources.
5. Students in junior-level high speed aerodynamics did a creditable job with analysis of a hydrogen-fuelled supersonic aircraft architecture, starting with conceptual design from an assignment done by freshmen in Introduction to Aerospace Engineering. This required considering issues from the Kyoto Protocol and Carbon Markets, Eastern Hemisphere demographics post-globalization, and airline ticket price components, in order to set their aerodynamics work in context. The following year the students in this class did a concept analysis of an aerodynamics-based system to defend against ballistic missiles, in order to alter the balance of power in favor of the defender. This required

consideration of geopolitics, the history of strategic deterrence, and various other topics outside aerodynamics. In the next year, students in this class are doing a conceptual analysis of a runway-based worldwide space access system capable of delivering 100,000 kg payloads to Low Earth Orbit at a very high rate of operations. This assignment requires rudimentary considerations of orbital mechanics, and somewhat in-depth consideration of propulsion systems, both of which are outside the purview of high speed aerodynamics. Here the culture and capabilities of cross-disciplinary learning are coming strongly into play.

6. In structures courses, instructors are setting assignments that use EXTROVERT capabilities, and in turn students are helping to develop more resources to go into EXTROVERT.

7. In the past several years, an average of 20-plus students each semester have been participating in cross-disciplinary Special Problems research with the author, leading to a number of publications, all of which are in (mostly peer-reviewed) international conferences or peer-reviewed journals. Most of these are in fora outside traditional aerospace engineering.

8. Over 80 articles, of which nearly 60 were peer-reviewed, have been published from our group over the past few years outside our traditional aerodynamics research area, about 75% of them including undergraduate co-authors.

9. Students are increasingly finding co-op and full-time positions well outside traditional haunts of aerospace engineers.

Conclusions

The paper argues why depth of comprehension is crucial in engineering education. Emphasis on depth does not come at the expense of breadth; in fact quite the opposite is true. Developments over the past decades provide cause for extreme concern, and a renewed emphasis on depth. One approach to providing both depth and breadth, and allowing learners to iterate on concepts, is presented: the EXTROVERT system that we have developed. While this is valuable for every learner (whether student, professor or alumnus in industry), the focus is on making it possible for the best learners and innovators to achieve results far beyond what their predecessors could achieve, capture their success, and use it to inspire the next generation of learners. The paper makes the (uncomfortable to some ASEE readers) point that change is needed from administrators and faculty, if depth is not to be lost. However, despite substantial and quite needless obstacles, student performance vindicates our approach. Experience of changing the culture in courses and undergraduate research is touched upon, and some metrics are presented to gauge the fact that the approach is effective.

In conclusion, the list provided at the beginning of the paper is repeated:

a. Graduates must know and be able to use what they are supposed to have learned. The idea that the bachelor's degree is just intended to provide a flavor and trigger interest in engineering, with actual competence coming through lifelong learning, runs into serious trouble in an environment where global corporations can recruit smart, competent graduates from all over the world who can start making an impact immediately.

b. There is a large opportunity for improvement in depth of learning. The reality of what is usually taken away by most of our students from the undergraduate program, leaves room for a large multiplier in improvement.

c. Technology can help by providing access to in-depth knowledge resources. Technology is best seen as a powerful aid to breadth and depth in engineering learning, and not as an entertainment/ attention-retaining aid. This allows the better 50 to 75 percent of our students to zoom out far ahead of where we could take prior classes.

d. Demanding depth is controversial and encounters stiff opposition. Instructors who try to increase the value and depth of their students' learning, can expect obstruction and harassment from a few students who have little intention of putting in the thought and effort to learn anything that requires such effort, faculty who pander to the pressure from the worst students, and administrators whose idea of earning their pay is to make these students happy.

e. Learners' comments vindicate our efforts. Cogent, detailed letters from our best students show a very high level of anger at the obstruction, and at the increasing genuflection of many professors and administrators at the altar of Student Happiness, ignoring the best interests of those who are interested in excelling in engineering.

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