Advocating Breadth in a World of Depth

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1 Abstract

A typical four-year engineering curriculum is chock-full of courses, concepts, and ideas. However, four years is simply not enough time to explore the vast landscape of engineering knowledge thoroughly. Thus trade-offs are made selecting material within a course as well as selecting courses within a curriculum. One of these trade-offs is depth versus breadth. At the extremes, the specialist is too narrow while the generalist is too shallow. Most curricula locate themselves between these two poles, with general engineering programs leaning somewhat towards breadth. One might think that students who choose general programs would be appreciative of the breadth of the curriculum. However, even here some students object to required courses that are not immediately and obviously applicable to their anticipated career path. How can we convince students that breadth is just as important, if not more so, than depth? As a case study, I describe my approach in an introductory electrical engineering course that is taught to students interested in a variety of engineering disciplines – many of whom are not necessarily interested in electrical engineering per se. Using a variety of pedagogical and curricular techniques, I dispel a number of myths related to the breadth versus depth debate.

2 Introduction

The classic trade-off between breadth and depth is sometimes summarized as follows: the generalist knows less and less about more and more, while the specialist knows more and more about less and less. In the extreme one either knows nothing about everything or everything about nothing. Every engineering program must stake its claim somewhere along this continuum, and general engineering programs tend to provide a little more breadth and thus a little less depth. This paper provides some justification for the choice of breadth. In section 3 some of the curricular constraints that force the trade-off are examined. Section 4 compares some of the advantages of depth to those of breadth. Sections 5 and 6 provide some specific methods of persuading students of the value of breadth. Section 7 concludes with some thoughts about the broader questions students deem vital.

3 Curriculum Constraints

Four years is the expected time to attain the entry level degree in engineering. There have been occasional calls for five-year programs, but very few institutions have taken the leap. The extra year seems like a very long time to most high school students choosing a college, so in order to attract students, a five-year program must either have some special focus, must be from a well-known school, or needs very good marketing. Of the 683 degree programs in the ASEE college profile database for 2002[1], 438 provided both a nominal program length and indication of ABET-accreditation. (There were 245 entries in the database that either did not report their program length or were not ABET-accredited.) Of the 438 degrees with both items (from 109 institutions), only a handful indicated a nominal program length of five years – 15 degrees from four institutions: Dartmouth, Drexel, University of Cincinnati, and University of Connecticut. Two of these schools allow students to obtain dual degrees: Dartmouth and University of Connecticut. The latter offers a EuroTechnology degree, which sends students to Germany as interns in the fifth year, allowing them to also obtain the B.A. degree. The University of Cincinnati reports B.S. degrees in “Aerospace Engineering and Engineering Mechanics”, “Chemical Engineering and Materials Engineering”, “Civil Engineering”, and “Electrical Engineering, Computer Engineering, and Computer Science”. Drexel University reports degrees in Architectural ,Biomedical, Chemical, Civil, Computer, Electrical, Environmental, Materials, and Mechanical engineering.

A fifth year for the entry level degree competes not only with shorter programs for a similar degree, but also with the Master’s degree. Calls have come from some quarters to make a Professional Master’s degree the entry level degree.[2] However, by and large, the Bachelor’s degree continues to be sufficient to enter the engineering work force. Thus the vast majority of programs are four years in length and it appears this will continue to be the standard for some time to come.

4 Breadth versus Depth

Given that the constraint of four years is unlikely to change, the pressure to provide more depth and more breadth must be contained and trade-offs are necessary. Each emphasis has its advantages and drawbacks.

4.1.1 Depth

A focus on depth has several advantages. First, a graduate with depth in one area is often attractive to employers looking for a precise combination of skills and abilities. An employer may be looking for expertise in a particular CAD tool (often as specific as a particular version of the software). They may be looking for expertise in a particular type of analysis, or experience with a particular class of materials. Second, depth in a field helps one pay attention to detail. One experienced in a domain has a mental checklist of all the things that could go wrong that must be double-checked, and all the subtle points that must be fine tuned. Third, depth provides experience that leads to expertise. An expert has a more comprehensive mental model of a domain. They are less likely to make mistakes because of their better model. They can better apply their knowledge to similar problems. They understand the assumptions and limitations of the domain better. Fourth, additional time on a subject area presumably allows the student to make more progress along Bloom's taxonomy[3] of educational objectives for the cognitive domain (knowledge, comprehension, application, analysis, synthesis, evaluation).

Many engineering curricula tend to focus on depth because they are designed by academics who themselves focus on depth in their own research. Academic research requires depth so that one is developing knowledge that has never been developed elsewhere. Replication of previous work is not considered useful.

4.1.2 Breadth

A focus on breadth has a counterpoint set of advantages. First, breadth gives the student the context necessary to avoid tunnel vision. The student learns to see the connections between things. Engineering in industry encourages reuse as a good business practice. Replication is savings. A broad knowledge of the field is necessary in order to identify potential reuse targets and also to know one's competition. Breadth prevents an engineer from becoming outdated as soon as the next version of a software tool is released. Second, broader understanding helps prevent misunderstanding of technical interfaces, misdiagnosis of interdependent problems, and miscalculation of complex models that span multiple disciplines. Third, contextually broad learning helps persuade the student that engineers, the designers of technology, do not design in a vacuum and the products they create reflect their creators. Thus they learn that technology is not neutral.[4] Fourth, breadth encourages a focus on fundamentals that are broadly applicable. Even when the technological details change (as they frequently do), the student in full command of fundamental principles is well prepared to tackle the next big thing, whatever it might be. Fifth, a broader experience prepares students to work in more than one area (perhaps even outside of engineering). In today's work world, career changes are common, so this preparation can be vital. In fact, employers who hire for a very narrow set of skills may consider that employee to be dispensable when those particular skills are no longer needed. Sixth, broad education typically includes stronger emphasis on teamwork and communication. These are essential abilities. In fact, many engineering employers indicate that they can find strong technical skills in most engineering graduates. For them, communication skills differentiate prospective hires. Of course those students who move into management ranks will put their communication skills to good use as well. Finally, while depth may be most helpful in the first few levels of Bloom's taxonomy, it is breadth that can be more beneficial for the higher levels, which require context. For example, synthesis can only be done when there are sufficient pieces to integrate together. Evaluation of alternative approaches can only be done when there are sufficient alternatives to make comprehensive comparisons.

Breadth is needed not just in curriculum, but in pedagogy. Students come to the classroom with different learning styles. For example, Howard Gardner's theory of multiple intelligences[5,6] posits that students have strengths in different sets of kinds of intelligence: Verbal-Linguistic, Mathematical-Logical, Musical, Visual-Spatial, Bodily-Kinesthetic, Interpersonal, Intrapersonal, Naturalist, and Existential.

Domain-specific knowledge does not transfer easily. Dienes and Altmann note that knowledge is less flexible when it is less consciously held: "People often do not notice that the known solution to a problem they have just come across could be used to solve a new problem in an analogous way."[7] Breadth provides potential solution methods that could be applied to a particular problem, though an engineer may not recognize it is applicable if the knowledge is not made conscious enough, while depth provides good experience in applying time-honored principles, but the accompanying tunnel vision prevents the engineer from coming across other possible approaches.

5 A Case Study

Calvin has a general engineering degree (for an overview of these types of programs, see Farison and Newberry[8].) Students at Calvin obtain a Bachelor of Science in Engineering (B.S.E.) degree, with a concentration in a particular discipline (chemical, civil, electrical & computer, or mechanical). All students take the same first two years, giving them a foundational background in each of the concentrations. They then pursue a concentration in more depth during the second two years. We find that this general approach is an advantageous balance to provide foundational education in engineering within a four year college career[9].

One of the courses in the first two years is ENGR204 "Circuit Analysis and Electronics", a course that introduces sophomore students to electrical engineering. It covers topics such as node-voltage circuit analysis, RLC transient response, op-amps, and more. Students in this course who are pursuing a concentration other than electrical engineering often ask why they need to take the class. This is the quintessential question for almost any course that does not precisely fit a student's perceived discipline. Engineers in particular focus on "what can I do with it?", whether the "it" is a gadget or a course. When the application is not immediately obvious, students can quickly lose interest. This poses a challenge to the instructor trying to teach engineering students, whether the subject is grammar or calculus or even engineering.

There are a number of pedagogical techniques to persuade students of the importance of breadth. First, one should use lots of examples – the more concrete, the better. But even with very good examples, if the context is not one with which the student immediately connects, she is likely to tune out. Thus additional approaches are necessary. Second, explicitly tell your students about goals for breadth. Many will be willing to withhold judgment, at least for a time, if there is an overt assertion of significance. Testimony from former students or from employers may carry more weight. Quoting an employer who has indicated the value of breadth will make some students take notice. Third, always couple theory with direct application – in this case, application to the student's own discipline. For example, one can find application of electrical engineering concepts in mechanical engineering products such as packaging of electronic components, motors, robotics, and manufacturing control systems. Mechanical engineers often use instruments that are based primarily on electrical engineering concepts (such as a strain gauge) and tools that are electrical engineering products (such as computers used for CAD). Similarly, civil engineers can apply electrical principles in using pumps and motors, chemical engineers in process control, and so forth. There are some textbooks available that attempt to introduce electrical engineering concepts by connecting it with other engineering disciplines. Fourth, it is important to recognize the indirect value of breadth. Particular details may change over time, but fundamental principles will serve the student well for years to come. The solution methods used in one discipline can often be applied to analogous problems in other disciplines. Struggling with difficult problems can lead to improved creativity and improved problem solving skills.

6 Myths about Breadth

It is important to commend the virtues of breadth and in doing so there are some common misconceptions that should also be dispelled.

6.1 Myth 1: Disciplines are distinct

Students often hold a very black and white view of the disciplines. They expect that every concept, every idea, all information can be neatly segregated and classified into a particular discipline. The separation between domains of knowledge is a high wall.

But the disciplines are not distinct. They are merely convenient packages of material – packages that our students must learn to reorganize as the need arises. Certain topics have been traditionally labeled as one discipline or another, but many topics must be called interdisciplinary, such as robotics, integrated circuit design, aeronautics, and control systems, to name a few. An example of incorporating this idea in the classroom is teaching on the topic of computer hard drives. Electrical engineers tend to focus on the control circuitry, the electromagnetic properties of the disk head, or perhaps the bus protocol used to transfer data. But the real hard drive also has sophisticated mechanical engineering in order to spin up the platter to thousands of RPMs and move the disk head quickly into a precise position very close to the platter. The real hard drive includes advanced chemical engineering and physics to develop the best platter material that allows magnetic bits to be densely packed.

6.2 Myth 2: Disciplinary methods are distinct

Students often expect that the methods and concepts of a domain are distinct – they do not apply in another domain. They do not easily recall material learned in an earlier course and rarely believe that the earlier material could be applicable.

But disciplinary methods are not distinct. This inability to apply methods across disciplines is a well-known blind spot. Educational researchers have long known that transfer of domain-specific knowledge is difficult. One explanation, based on situated cognition theory is that students construct mental models to help them deal with a certain body of knowledge. When faced with a new concept that students do not perceive fits the boundaries of the existing model, it is often easier to construct a new, separate mental model than to modify an existing model to fit the new concept.[10] Preventing these unhelpful distinctions may require not only pointing out a method the students already know, but applying it in the new situation using a pattern familiar to the students. For example, a circuit problem might be solved using node-voltage analysis, resulting in a set of simultaneous equations. If students have also seen simultaneous equations result from solving a set of forces in static equilibrium, then a similar mathematical approach (perhaps Gaussian elimination) should be used so that students make the connection that analogous mathematical models can be solved using similar methods. If dissimilar methods are used (perhaps Kramer's Rule), the students will tend to miss the helpful analogy and not realize the same tools are applied in both cases.

6.3 Myth 3: Disciplines do not converse

Students often assume that there is very little communication between disciplines. Each domain is nicely parceled out and no interdisciplinary conversations are necessary. This idea comes naturally to them, since the academic departments at the institutions they attend are similarly divided.

But outside of the rarified air of academics, disciplines must mix and converse and interact by necessity. Almost every substantial engineering project requires multiple disciplines to work closely together. Thus students need to know the jargon of these other disciplines, at least at a rudimentary level. This often comes home to students in our senior design projects course when interdisciplinary teams of varying engineering disciplines tackle a real world project.

6.4 Myth 4: Future knowledge needs are fully predictable

Students sometimes think they know everything, but their professors are usually rather adept at disabusing them of this notion. Even then, sometimes students think they know what they need to know. That is, they have very narrow bounds on what they believe is necessary learning. While the question "why do we need to know this?" can be a good prod to the instructor to provide concrete examples of application, it can also be a telltale sign that the student has already tuned out, perceiving that the topic at hand is outside the bounds of their future knowledge needs.

But future knowledge needs are quite unpredictable. Changes in career direction are common, and almost every engineering job evolves over time, requiring new knowledge. Thus students need knowledge in a variety of areas and various domains that are likely to have some impact on their careers. Students who have held internships sometimes subconsciously fit their perceived knowledge needs to the needs they encountered during their intern experience. But of course that experience was by its very nature limited in scope. This myth is possibly the most difficult to dismiss, because it is rooted in an attitude often tinged with arrogance and sometimes cynicism. I have found that these students sometimes respond when told of fellow students that did not get a job that they expected to win because (in the words of the interviewer), they were "know-it-alls who weren't willing to learn." The students often are surprised that an employer might reject them because of their attitude, even if they have plenty of talent!

6.5 Myth 5: Applicability is the sole measure of value

The question of applicability is an important one. Efficiency is an important goal, and it also applies to the educational process. With limited time, it seems reasonable to focus on the learning that most directly applies.

But applicability is a slippery concept. What is applicable today may be obsolete tomorrow. The particular details of a problem may not actually be of significance (details change from day to day). Rather, the discipline of problem-solving may be the most valuable learning that the engineering student can experience. Assimilating the skills of patience, creativity, and organization may be most important, but these are learning objectives that are often obscured. One way I have gotten students to see beyond the moment is to start a class by asking them to list the five most important things they will learn in college. When asked to take a broader perspective, ideas like "problem solving" or "communication" arise naturally.

7 Conclusion

This paper has advocated an emphasis on breadth, but depth is also necessary. Either extreme leaves important gaps in an engineering student's preparation; both are necessary. It is simply a matter of balance.

The question "Why do we need to know this?" was noted as a common student question earlier. This query may have a deeper question hidden behind it – the student may actually wonder "Why am I here?" Indeed, why study this topic instead of that? Why pursue this particular engineering discipline, or engineering at all? What is the purpose of a college education? Is it merely to get a good job? At bottom, this question may really be a variant on the age-old question of the meaning of life. Many students are desperate to confirm that they have made a wise career choice. Engineering can certainly be a very meaningful choice for many of our students. But perhaps the idea of vocation is useful here. Vocation, broadly understood, is more than simply career choice. It is following one's calling and fulfilling one's destiny. As Buechner describes calling, it "is the place where your deep gladness and the world's deep hunger meet."[11] A curriculum that emphasizes breadth can help students to see the big picture. The contextualization of their education can in turn help them to better understand their own vocation.

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[1] http://www.asee.org/about/publications/profiles

[2] "Should We Mandate the Master's?" *ASEE Prism*, v9, n1, September 1999, pp. 20-21.

[3] Bloom, B. S. *Taxonomy of Educational Objectives: Handbook 1, Cognitive Domain*. Longman, New York, 1956.

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[5] Gardner, H. *Frames of Mind: The Theory of Multiple Intelligences*. New York: Basic Books, 1983.

[6] Gardner, H. *Intelligence Reframed*. New York: Basic Books, 1999.

[7] Dienes, Z. and Altmann, G, "Transfer of implicit knowledge across domains? How implicit and how abstract?" In D. Berry (Ed.), *How Implicit is Implicit Learning?* Oxford: Oxford University Press, 1997, pp 107-123.

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[11] Buechner, Frederick, *Wishful Thinking: A Theological ABC*, New York, Harper & Row, 1973, p. 95.

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