Math Usage by Practicing Engineers: What does it mean to Curriculum Planners?

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Abstract

Engineering programs are constantly assessing the material required to earn an engineering degree. This assessment leads to squeezing in additional courses, often at the expense of requiring additional credits beyond that for a typical Bachelors degree. The common practice of including new material while not changing what already exists is pushing the number of required credits for an engineering degree in excess of what should be expected. A fundamental question not typically addressed is “What material should be removed from the old curriculum in order to make way for new material?” One possible method for addressing this question is to compare what is taught in academia versus what is needed by a practicing engineer. Faculty in the College of Engineering at Idaho State University have developed, administered, and analyzed a survey asking practicing engineers their usage and required conceptual understanding of certain math topics to perform their job functions. It was decided at this time to focus only on the math topics and leave the remainder of the engineering programs for future efforts. Although the survey participants are centered on the geographic area of Idaho State University (south-eastern Idaho), the topics covered in core math courses are typical of what is taught at other universities. This paper presents the results of this survey, discusses some of challenges encountered in conducting this type of evaluation, as well as some conclusions that can be supported from the data.

Introduction

A National Science Foundation report expressed the following perspective on engineering education reform: “We need processes whereby curricula within existing departments can be renewed more rapidly. In addition, we need processes for more dramatic change, enabling curricula to adapt quickly to societal needs, analogous to “flexible and agile” manufacturing techniques. Just as we need mechanisms for quickly assembling new programs we need mechanisms for disassembling them when their time is past “¹.

The United Kingdom recently established a Learning and Teaching Support Network (LTSN). The aim of the LTSN is to provide support to academics in order to improve the provision of learning and teaching. In 2001 the LTSN Subject Centre conducted a needs analysis survey of

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both industry and academia. There were 410 responses from industry and 315 responses from academia. This survey data suggests that: “The difference in the profile of the engineering graduate as demanded by industry and as supplied from academic appears to be getting greater and greater.”²

The lack of institutional mechanisms to identify and disassemble obsolete curriculum is a barrier to substantial engineering curriculum reform. A first step in this process is developing an assessment tool to identify curriculum material that is no longer relevant. All engineering programs that are accredited by Accreditation Board for Engineering and Technology (ABET) must have a continuing assessment process³. The assessment process must demonstrate that the defined outcomes of the program are being measured. The most commonly adopted assessment tools to satisfy these requirements are employer and alumni surveys. These survey instruments can effectively identify curriculum weakness and omissions; however they generally do not focus attention on areas of the curriculum that may have become obsolete. Employer and alumni surveys are designed to answer the question: What education or skills do graduates need to be successful in today’s market? The question that remains unanswered by these survey instruments is: What material is currently in the curriculum that is no longer relevant to current practice?

In 2003 the engineering faculty at Idaho State University (ISU) began a comprehensive assessment of the relevancy of the current curriculum to the engineering profession. A literature search revealed very little published data directly relating the curriculum material to the needs of the profession. Therefore, the faculty at ISU pioneered a survey to collect this type of data. It was also felt that a small pilot survey should be conducted to identify the pertinent issues related to this new type of assessment. The first area that was selected for evaluation was the math courses that are common to most engineering disciplines.

This survey attempts to determine the math curriculum that is most relevant to the engineering profession. But perhaps more significant were the challenges that were encountered in defining a instrument to collect and interpret this data. This paper will discuss the design of the survey instrument, the survey results, and some of the challenges and conclusions that can be extrapolated from the data.

Survey Design

The objective of this survey is to assess the relevancy of the current math curriculum to the needs of the current practice of engineering. Thus, this survey asked working engineers to describe their usage of the math curriculum material to successfully fulfill their job functions. The current curriculum at Idaho State University is built on an interdisciplinary core of engineering courses. All engineering majors are required to take these core courses. Consequently, the primary objective of this survey was to evaluate the relevancy of the core math courses for all engineering disciplines. The core mathematics courses that were included in the survey are: Calculus I, Calculus II, Differential Equations, and Numerical Analysis of Engineering of Engineering Problems. Consequently, the math curriculum included in this survey does not include all the math courses that may be required for each engineering discipline.

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The faculty also wanted to determine if there were significant differences in the math usage based on type of job function, engineering discipline, terminal degree, and number of years employed. The respondents were asked to respond to four questions in an effort to collect some profile data to permit the responses to be categorized in this manner. First respondents were asked to define their primary job function from a list of five choices: Design, Test, Analyst, Management, or Other. Next the respondents were asked to declare their engineering discipline as either: Electrical, Civil, Mechanical, Nuclear, or Other. Respondents were then asked to declare their terminal engineering degree: Bachelors, Masters, or Doctorate. Finally, the respondents were asked how many years they had been employed as engineers.

To construct a list of math topics to be included in the survey, the faculty simply took the textbooks that are used in the undergraduate engineering program's required math courses and constructed a list of the topics from the table of contents of each text. Since most courses have required textbooks this was a rather straightforward approach to defining the content of the survey. It should also be noted that although no one textbook is used at all universities, the topics included in different undergraduate texts are generally very similar.

The data collection was separated into two parts. The first part of the survey was designed to assess the usage of the selected math topics by practicing engineers. The second part was designed to assess if a basic conceptual understanding of the mathematical concepts is required to perform the respondent's job functions. It was felt by the faculty that although a particular job may not require an engineer to be proficient in the use of some mathematical calculation techniques some conceptual understanding may be required. The faculty wanted to assess both actual usage of mathematical material and required understanding of the underlying concepts.

In the first part of the survey the respondent was given a math topic such as "differentiation". He or she was then asked to declare the usage of this topic in their present position with one of the following choices: Never, Seldom, or Frequently.

In the second part of the survey respondents were asked to indicate if a basic conceptual understanding of a given math topic is required to perform their job functions. The respondent was asked to respond with either "yes" or "no" to each topic. A "yes" response indicates that some conceptual understanding is required, while a "no" response indicates no understanding is required.

The survey was administered to two different groups: the members of Idaho State University's College of Engineering Advisory Board and recent alumni of the College of Engineering. Each member of the advisory board also solicited responses from several other engineers in their organizations. These responses represent about half of the total responses. The remaining survey responses are from ISU alumni from the past five years.

Survey Results

A total of 96 engineers responded to our math usage survey. The responses are tabulated in tables 1 through 3. The data are sorted by the “Frequently” and “Yes” responses.

Table 1. Profile of Respondents							
Primary Job Function		Engineering Discipline		Terminal Degree		Work Experience	
Design	39	Electrical	25	Bachelors	73	0-3 years	33
Test	7	Mechanical	18	Masters	20	3-7 years	25
Analyst	13	Civil	29	Doctoral	3	7-10 years	3
Management	20	Nuclear	4			10–20 years	17
Other	17	Other	20			More than 20 years	18

Table 2. Summary of Part I. Math Usage			
TOPIC	NEVER	SELDOM	FREQUENTLY
Numerical Methods	26	45	25
Limits and Rates of Change	22	51	23
Mean Value Theorem/Curve Sketching	28	45	23
3-D Analytic Geometry and Vectors	42	36	18
Differentiation	39	43	14
First-Order Differential Equations	44	39	13
Integrals	43	40	13
Parametric Equations & Polar Coordinates	39	48	9
Laplace Transforms	63	24	9
Partial Derivatives	58	30	8
Techniques of Integration	48	42	6
Vector Calculus	58	32	6
Nonlinear Differential Equations	70	20	6
Multiple Integrals	65	26	5
Infinite Sequences and Series	66	26	4

Table 3. Summary of Part II. Conceptual Understanding Required		
Topic	Yes	No
Differentiation	84	12
Integration	82	14
Numerical Methods	77	19
Differential Equations	66	30
Vector Calculus	50	46
Infinite Sequences and Series	37	59

Challenges

First and foremost it must be stated that the survey respondents are employed primarily in southeast Idaho. Consequently, the sample size is certainly not large enough to draw any general conclusions that would be applicable to all engineering programs in the United States. The sample size was not large enough to have confidence in any noted differences in the responses based on job function, discipline, terminal degree and number of years of work experience. As a matter of interest, some differences in the responses were noted when the data were sorted by job function, discipline, terminal degree and number of years of work experience (see Appendix A).

The results may also be subject to some sampling and measurement error. The sample was not truly random. The respondent's interpretation of "Never, Seldom, and Frequently" is another possible source of error. Perhaps the greatest challenge is relating the data to curriculum planning. For instance, Numerical Methods scored high in usage survey while Infinite Series and Sequences usage was low. It is interesting to note that many numerical methods are based on Infinite Series and Sequences. Is it possible that the respondents were not fully aware of their use of Infinite Series and Sequences? Or is it possible that engineers are using Numerical Methods in a manner that does not require knowledge of Infinite Series and Sequences? These responses highlight that practicing engineers and academics have different perspectives on the curriculum material.

There were not many responses from engineers with 7 –10 years of experience. Our advisory council is made up primarily of engineers with over 10 years of experience. The second population was from the past 5 years alumni. Some of these engineers had less than one year of work experience. In retrospect, it would have been better to include only engineers with at least one year of work experience. Some respondents with limited work experience were not confident in the requirements of their jobs to respond to some of math usage questions in the survey.

Many respondents were not comfortable in selecting between the choices given for primary job function. It was not uncommon for the respondent to comment that their jobs included several of the functions provided in the selection list. When this occurred the respondent was asked which of the functions occupied most of their time. It became apparent during the administration of the survey that more detailed information relating to job function would have been very valuable. It is also important to determine if respondents with the same type of job provided similar survey responses.

Conclusions

It is difficult to conclude if the usage of any math topic is below or above that of any other engineering curricula topic without a reliable benchmark for comparison. This will not be possible until more data are collected and analyzed. Math and basic science are certainly the foundation of any engineering program. This fact will not change in the foreseeable future.

Most engineers feel that at least a conceptual understanding of majority of the math topics is required to perform their job functions even though the survey indicates that the actual usage of these same calculation techniques is significantly less. The one possible exception is Infinite Sequences and Series. Several respondents commented that they felt that the math curriculum was also beneficial in teaching them how to logically formulate solutions to problems.

The most significant finding from the survey data was that there are marked differences in the use of certain mathematical concepts by practicing engineers. There is a significant difference in the usage of the top three topics: Numerical Methods, Limits and Rates of Change, and The Mean Value Theorem / Curve Sketching, and all other topics. While the bottom three topics: Nonlinear Differential Equations, Multiple Integrals, and Infinite Sequences and Series, appear to be used significantly less than all other topics. It is also interesting to note the differences in the responses when the data is sorted by the profile categories i.e., Primary Job Function, Engineering Discipline, Terminal Degree, or Work Experience (see Appendix A) .

The greatest difficulty encountered was using the results of this survey as a curriculum-planning tool. The traditional math curriculum is a logical progression of principles and concepts. The survey responses did not always correspond to this logical sequence. Some topics that involve concepts related to or even built on other topics did not yield similar results. This could imply that engineers are using these math topics but seldom need to understand the underlying theory. It could also imply that the respondents are simply not cognizant of all of the mathematical concepts that they are using to perform their jobs. Some of the inconsistencies in the responses imply that the respondents did not recall enough detail about the subject material in the survey to provide a useful evaluation. In either case, this issue needs to be resolved before the survey results can be fully utilized as a curriculum-planning tool.

In an effort to verify the survey results, a similar survey was given to a group of fourteen engineers that are employed in an electrical consulting firm. The engineers employed in this firm were primarily electrical design engineers with 3-7 years of work experience. The results of this secondary data source compare favorably with the results of this survey.

It is important that the results of this survey are considered in the broader context of the entire engineering curriculum. The relative importance of the knowledge of mathematics in the engineering curriculum is addressed by a survey conducted by the engineers at the Boeing Company⁴. This much more extensive survey with 420 responses representing fifteen companies, attempts to assign a “level of importance” to some topics related to engineering knowledge and experience. Participates of this survey are mainly mechanical engineers employed in the aerospace and defense-related companies. The relative level of importance assigned to mathematical related concepts is high.

This survey data should not be used in isolation to derive requirements for an engineering curriculum. The reality of curriculum planning is that inclusion of new subject material often means removing existing material. Therefore, we feel that assesses not only the desired program objectives, but also the relevancy of the present curriculum is an important component of the continuous quality refinement of our program. Consequently, a systematic method needs to be refined for making not only decisions regarding proposed course material additions but also the removal of course material when its time is past.

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Biography

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Appendix A

The tables below show the survey results for selected profile categories. The first table in the sequence shows the profile of respondents for both the Math Usage and Conceptual Understanding tables that follow. The selection criteria is highlighted in the profile table. The survey responses in the corresponding Math Usage and Conceptual Understanding tables are also sorted by most frequently used topics to least frequently used topics for ease of comparison. The number of responses in some of these categories is not sufficient to support a high degree of statistical confidence in the results.

Table A-1. Primary Job Function - Design							
Primary Job Function		Engineering Discipline		Terminal Degree		Work Experience	
Design	39	Electrical	7	Bachelors	32	0-3 years	14
Test		Mechanical	7	Masters	7	3-7 years	13
Analyst		Civil	16	Doctoral	0	7-10 years	2
Management		Nuclear	0			10-20 years	6
Other		Other	9			More than 20 years	4

Table A-2. Math Usage for Primary Job Function - Design			
TOPIC	NEVER	SELDOM	FREQUENTLY
3-D Analytic Geometry and Vectors	17	13	9
Mean Value Theorem/Curve Sketching	15	17	7
Numerical Methods	16	16	7
Parametric Equations & Polar Coordinates	21	12	6
Laplace Transforms	28	7	4
Limits and Rates of Change	14	22	3
Integrals	16	20	3
Differentiation	15	22	2
First-order Differential Equations	21	16	2
Vector Calculus	22	15	2
Techniques of Integration	19	19	1
Infinite Sequences and Series	28	10	1
Multiple Integrals	28	10	1
Partial Derivatives	24	15	0
Nonlinear Differential Equations	31	8	0

Table A-3. Conceptual Understanding for Primary Job Function - Design		
Topic	Yes	No
Differentiation	34	5
Integration	32	7
Numerical Methods	31	8
Differential Equations	25	14
Vector Calculus	22	17
Infinite Sequences and Series	15	24

Table A-4. Primary Job Function - Management							
Primary Job Function		Engineering Discipline		Terminal Degree		Work Experience	
Design		Electrical	6	Bachelors	15	0-3 years	6
Test		Mechanical	5	Masters	5	3-7 years	2
Analyst		Civil	7	Doctoral	0	7-10 years	0
Management	20	Nuclear	1			10-20 years	2
Other		Other	1			More than 20 years	10

Table A-5. Math Usage for Primary Job Function - Management			
TOPIC	NEVER	SELDOM	FREQUENTLY
Mean Value Theorem/Curve Sketching	7	8	5
Limits and Rates of Change	2	15	3
Numerical Methods	4	13	3
Parametric Equations & Polar Coordinates	6	12	2
3-D Analytic Geometry and Vectors	9	9	2
Differentiation	13	5	2
Integrals	13	5	2
Infinite Sequences and Series	17	1	2
Nonlinear Differential Equations	17	1	2
First-order Differential Equations	12	7	1
Techniques of Integration	15	4	1
Partial Derivatives	15	5	0
Multiple Integrals	15	5	0
Laplace Transforms	16	4	0
Vector Calculus	17	3	0

Table A-6. Conceptual Understanding Required for Primary Job Function - Management		
Topic	Yes	No
Numerical Methods	18	2
Differentiation	17	3
Integration	17	3
Differential Equations	12	8
Vector Calculus	7	13
Infinite Sequences and Series	5	15

Table A-7. Engineering Discipline - Mechanical							
Primary Job Function		Engineering Discipline		Terminal Degree		Work Experience	
Design	7	Electrical		Bachelors	14	0-3 years	9
Test	0	Mechanical	18	Masters	4	3-7 years	5
Analyst	2	Civil		Doctoral	0	7-10 years	0
Management	5	Nuclear				10-20 years	3
Other	4	Other				More than 20 years	1

Table A-8. Math Usage for Engineering Discipline - Mechanical			
TOPIC	NEVER	SELDOM	FREQUENTLY
Limits and Rates of Change	5	8	5
3-D Analytic Geometry and Vectors	8	6	4
Integrals	9	5	4
Mean Value Theorem/Curve Sketching	7	8	3
Numerical Methods	6	9	3
Differentiation	8	8	2
Vector Calculus	13	3	2
Laplace Transforms	13	3	2
Parametric Equations & Polar Coordinates	8	9	1
Techniques of Integration	9	8	1
First-order Differential Equations	9	8	1
Partial Derivatives	12	5	1
Multiple Integrals	12	5	1
Nonlinear Differential Equations	14	3	1
Infinite Sequences and Series	13	5	0

Table A-9. Conceptual Understanding Required for Engineering Discipline - Mechanical		
Topic	Yes	No
Differentiation	17	1
Integration	16	2
Numerical Methods	14	4
Differential Equations	13	5
Vector Calculus	11	7
Infinite Sequences and Series	8	10

Table A-10. Engineering Discipline - Other							
Primary Job Function		Engineering Discipline		Terminal Degree		Work Experience	
Design	9	Electrical		Bachelors	17	0-3 years	2
Test	0	Mechanical		Masters	1	3-7 years	10
Analyst	3	Civil		Doctoral	2	7-10 years	1
Management	1	Nuclear				10-20 years	5
Other	7	Other	20			More than 20 years	2

Table A-11. Math Usage for Engineering Discipline - Other			
TOPIC	NEVER	SELDOM	FREQUENTLY
Mean Value Theorem/Curve Sketching	4	9	7
Limits and Rates of Change	4	12	4
Parametric Equations & Polar Coordinates	7	9	4
3-D Analytic Geometry and Vectors	11	5	4
Numerical Methods	3	14	3
Differentiation	4	13	3
First-order Differential Equations	7	10	3
Partial Derivatives	11	7	2
Integrals	7	12	1
Laplace Transforms	15	4	1
Techniques of Integration	7	13	0
Infinite Sequences and Series	10	10	0
Vector Calculus	13	7	0
Nonlinear Differential Equations	13	7	0
Multiple Integrals	16	4	0

Table A-12. Conceptual Understanding Required for Engineering Discipline - Other		
Topic	Yes	No
Differentiation	18	2
Integration	17	3
Numerical Methods	17	3
Differential Equations	16	4
Vector Calculus	12	8
Infinite Sequences and Series	10	10

Table A-13. Engineering Discipline - Civil							
Primary Job Function		Engineering Discipline		Terminal Degree		Work Experience	
Design	16	Electrical		Bachelors	20	0-3 years	13
Test	1	Mechanical		Masters	8	3-7 years	7
Analyst	3	Civil	29	Doctoral	1	7-10 years	0
Management	7	Nuclear				10-20 years	5
Other	2	Other				More than 20 years	4

Table A-14. Math Usage for Engineering Discipline - Civil			
TOPIC	NEVER	SELDOM	FREQUENTLY
3-D Analytic Geometry and Vectors	9	13	7
Mean Value Theorem/Curve Sketching	9	15	5
Numerical Methods	9	16	4
Differentiation	16	9	4
Limits and Rates of Change	7	19	3
Integrals	14	13	2
Techniques of Integration	18	9	2
Vector Calculus	18	9	2
Multiple Integrals	21	6	2
Parametric Equations & Polar Coordinates	10	18	1
Partial Derivatives	17	11	1
First-order Differential Equations	18	10	1
Infinite Sequences and Series	23	5	1
Nonlinear Differential Equations	24	4	1
Laplace Transforms	26	2	1

Table A-15. Conceptual Understanding Required for Engineering Discipline - Civil		
Topic	Yes	No
Integration	26	3
Numerical Methods	25	4
Differentiation	24	5
Differential Equations	18	11
Vector Calculus	14	15
Infinite Sequences and Series	5	24

Table A-16. Engineering Discipline - Electrical							
Primary Job Function		Engineering Discipline		Terminal Degree		Work Experience	
Design	7	Electrical	25	Bachelors	21	0-3 years	9
Test	6	Mechanical		Masters	4	3-7 years	3
Analyst	2	Civil		Doctoral	0	7-10 years	2
Management	6	Nuclear				10-20 years	3
Other	4	Other				More than 20 years	8

Table A-17. Math Usage for Engineering Discipline - Electrical			
TOPIC	NEVER	SELDOM	FREQUENTLY
Numerical Methods	8	5	12
Limits and Rates of Change	5	12	8
Mean Value Theorem/Curve Sketching	7	11	7
Laplace Transforms	9	11	5
First-order Differential Equations	10	11	4
Parametric Equations & Polar Coordinates	12	10	3
Integrals	13	9	3
Infinite Sequences and Series	17	5	3
Differentiation	11	12	2
3-D Analytic Geometry and Vectors	12	11	2
Vector Calculus	13	10	2
Techniques of Integration	14	10	1
Multiple Integrals	16	8	1
Partial Derivatives	18	6	1
Nonlinear Differential Equations	19	6	0

Table A-18. Conceptual Understanding Required for Engineering Discipline - Electrical		
Topic	Yes	No
Differentiation	21	4
Integration	19	6
Numerical Methods	17	8
Differential Equations	15	10
Vector Calculus	12	13
Infinite Sequences and Series	11	14

Table A-19. Work Experience 0-3 Years							
Primary Job Function		Engineering Discipline		Terminal Degree		Work Experience	
Design	14	Electrical	9	Bachelors	28	0-3 years	33
Test	6	Mechanical	9	Masters	5	3-7 years	
Analyst	0	Civil	13	Doctoral	0	7-10 years	
Management	6	Nuclear	0			10-20 years	
Other	7	Other	2			More than 20 years	

Table A-20. Math Usage for Work Experience 0-3 Years			
TOPIC	NEVER	SELDOM	FREQUENTLY
Limits and Rates of Change	11	15	7
Mean Value Theorem/Curve Sketching	11	15	7
Numerical Methods	13	14	6
3-D Analytic Geometry and Vectors	17	12	4
Differentiation	19	11	3
First-order Differential Equations	17	14	2
Integrals	22	9	2
Techniques of Integration	19	13	1
Vector Calculus	22	10	1
Multiple Integrals	25	7	1
Infinite Sequences and Series	25	7	1
Nonlinear Differential Equations	26	6	1
Laplace Transforms	27	5	1
Parametric Equations & Polar Coordinates	18	15	0
Partial Derivatives	23	10	0

Table A-21. Conceptual Understanding Required for Work Experience 0-3 Years		
Topic	Yes	No
Numerical Methods	29	4
Differentiation	28	5
Integration	27	6
Differential Equations	25	8
Vector Calculus	18	15
Infinite Sequences and Series	7	26

Table A-22. Work Experience More than 20 Years							
Primary Job Function		Engineering Discipline		Terminal Degree		Work Experience	
Design	4	Electrical	8	Bachelors	10	0-3 years	
Test	0	Mechanical	1	Masters	8	3-7 years	
Analyst	3	Civil	4	Doctoral	0	7-10 years	
Management	10	Nuclear	3			10-20 years	
Other	1	Other	2			More than 20 years	18

Table A-23 Math Usage for Work Experience More than 20 Years			
TOPIC	NEVER	SELDOM	FREQUENTLY
Numerical Methods	3	9	6
3-D Analytic Geometry and Vectors	7	6	5
Limits and Rates of Change	2	12	4
Parametric Equations & Polar Coordinates	5	9	4
Mean Value Theorem/Curve Sketching	7	7	4
Differentiation	7	8	3
First-order Differential Equations	7	8	3
Integrals	7	8	3
Nonlinear Differential Equations	11	4	3
Techniques of Integration	9	7	2
Partial Derivatives	10	6	2
Infinite Sequences and Series	14	2	2
Multiple Integrals	9	8	1
Laplace Transforms	10	7	1
Vector Calculus	10	8	0

Table A-24. Conceptual Understanding Required for Work Experience More than 20 Years		
Topic	Yes	No
Numerical Methods	15	3
Differentiation	15	3
Integration	15	3
Differential Equations	9	9
Vector Calculus	9	9
Infinite Sequences and Series	7	11