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On Scope and Assessment in Modern Engineering Education*

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As the field of engineering incorporates new technologies, the appropriate scope of undergraduate education in engineering continues to grow. It appears unlikely that course breadth can be widened to accommodate this growth, at every institution, by increasing the length of the undergraduate engineering curriculum. Therefore, with increases in breadth must come sacrifices in depth of coverage for many subjects. This paper explores the tradeoffs associated with engineering course scope, and discusses the possible remedies to engineering course overloading. Choices made regarding scope of the engineering course can affect, and be affected by, the methods used to assess student performance. But, as with course scope, any choice made between assessment methods is also fraught with tradeoffs. Conclusions are drawn and recommendations are made, based on a solicitation and analysis of mechanical engineering student and academic staff opinion on course scope and assessment.

INTRODUCTION

AS THE FIELD of engineering incorporates new technologies, the appropriate scope of undergraduate education in engineering continues to grow. The core material remains important since fundamentals like Maxwell's equations, the Navier-Stokes equations, Kirchoff's rules, and Newton's laws have not begun to lose their relevance. Neither have basic design skills like proper tolerancing [1]. Exposure of engineering students to the humanities and social sciences also continues to be prudent [2]. Moreover, newer material crucial to the success of modern engineers is also being justifiably added to the undergraduate curriculum. Examples of this in the mechanical discipline, for instance, include computer-integrated manufacturing [3], data acquisition systems, mechatronics [4], computer-aided design, modern management practice [5, 6].

It would seem that unless the undergraduate course in engineering is substantially lengthened, coverage of key subjects may be exceedingly abbreviated in order to make time for the inclusion of new topics. Alternatively, and with just as undesirable a consequence, important new areas of engineering may be omitted in order to insure a firm basis in traditional and fundamental concepts. It is the present author's experience that this course scope dilemma is quite extreme in the mechanical engineering discipline, due to the great diversity of sub-disciplines it encompasses (e.g. fluid dynamics, solid mechanics, dynamics and kinematics, heat and mass transfer, thermodynamics, design, manufacturing technology, power transfer and control systems, etc.). However, previous authors have also reported the presence of the dilemma in other engineering disciplines [7].

ENGINEERING COURSE IN THE CONTEXT OF A GROWING FIELD

In an environment of increasing competition for limited resources, it appears unlikely that important new topics can be included at every institution by increasing the length of the undergraduate engineering curriculum. The extent of the problem often leaves engineering educators with two basic remedies or options:

1. Exclude from the curriculum important subject matter which should reasonably be included.
2. Attempt to cover all important subject areas, dedicating less time to each specific area than was previously given.

It may at first seem that option 2 is superior to option 1, but this may not be the case. If an educator brushes over large amounts of important material without spending enough time to insure full comprehension along the way, and assessment standards are not also lowered, average student marks are likely to fall. This is an undesirable effect since it reduces the ratio of successful course graduates and so is counterproductive to the goal of educators. On the other hand, under this scenario, if assessment standards *are* lowered, student confidence in their education might suffer since many students may achieve high marks without being able to work fundamental problems. Upon possible failure to meet industry standards, many graduates might even feel that the marking system under which they 'succeeded' was dishonest

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(at the time dishonest in their favor, but dishonest nonetheless). This might reduce alumni-fostered industrial collaboration with academia.

On the other hand, it may seem that option 1 is the more favorable option, since it would produce graduates with solid skills, although in fewer areas. This might ultimately lead to graduates with increased confidence in their skills, since their embellished (and therefore expected) competencies would more closely match their actual competencies. For example, under this scenario, although graduates may not list as many areas of competency in an industrial job interview, they would be confident in their problem-solving skills in those areas. Furthermore, when presented with problems in new areas, the graduate might approach the learning prerequisite for solving those problems in a thorough manner (so as to attain a deep understanding) as was done in the restricted areas covered in formal education. Thus a graduate's approach to problem solving in a new area would stem from previous successes in different areas rather than previous failures in the same (but inadequately treated) area. This is a manifestation of the argument that, in the university environment, students 'learn to learn'. However, students might perceive such a deep and narrow curriculum as early specialization. In this case, such students might be make career-limiting decisions in relative ignorance, and specialization might be most profitably delayed until after entering the workplace.

The best choice among these options is not obvious, and thus coping with the problem of course overloading in engineering education is non-trivial. Since such course overloading is almost inevitable as the field of engineering develops, there is a strong contemporary need for further investigation into the possible remedies and associated tradeoffs. This need motivated a solicitation and analysis of mechanical engineering student and staff opinions on course scope, which took the form of the first of two questionnaires described in this paper.

STUDENT PERFORMANCE ASSESSMENT

Choices made regarding scope of the engineering course can affect, and be affected by, the methods used to assess student performance. This is true because problem solving is central to engineering assessment, and problem solving ability is related to the depth of topic coverage. For example, in an institution that embraces a broad and shallow approach to engineering topic coverage, the presence of students who are gifted at memorization could penalize other students, *but only if* students are assessed relative to each other. This would be considered unfavorable by those educators who, like the present author, believe that memorization is a skill which is less important to engineers than analytical ability. The institution could address the above hypothetical problem *either* by changing the assessment system (to one which assesses student performance against a fixed standard rather than in relationship with the performance of other students), *or* by embracing a more narrow and deep approach to the course scope. But, similar to the dilemma regarding course scope, any choice made between assessment methods is also fraught with tradeoffs.

Performance assessment methods based solely on the relative performance between students (referred to as 'relative', 'competition-based', or 'norm-based' assessment schemes) are fundamentally different from assessment methods under which student performance is measured against a fixed standard (referred to as 'absolute', or 'criterion-based' assessment schemes). This fundamental difference can be expressed in terms of what can, and cannot, be controlled under each approach. An institution using a norm-based assessment scheme is able to ensure a minimum quantity of graduates; indeed the percentages of students which pass, fail, or excel, are the quantities under control by the assessment method. However, such quantity control itself precludes the possibility of controlling the quality of graduates independently. Furthermore, shifts in the mean performance or capabilities of the students, which could result from an outside influence such as the merit of a lecturer or text, cannot be detected under norm-based assessment schemes.

Conversely, an institution using a criterion-based assessment scheme cannot independently control the quantity of graduates (i.e. pass rate), so long as the standard of quality (the criterion) is held fixed. Quality *is* controlled. The percentages of students which pass, fail, or excel, are not under control by the assessment method, but rather depend only on student performance and the choice of the fixed assessment criterion. Shifts in mean student performance, whether by chance or as a result of a the merit of a lecturer or text, are immediately apparent as a change in pass rate.

Some of the germane characteristics of norm-based and criterion-based assessment schemes are tabulated in Table 1. Whether specific items of the table are considered to be merits or defects of the scheme depend on the goals of the institution.

If, in practice, the difficulty of the criterion chosen for a criterion-based assessment scheme is set so that a desired pass rate is achieved for an initial group of students, one might then make the argument that the criterion-based assessment scheme is no more than a norm-based assessment scheme ' in disguise' [8]. However, the present author wholeheartedly disagrees with such arguments, since once the assessment criterion is fixed and upheld in a criterion-based scheme, the germane differences between the assessment schemes (as listed in Table 1) do not depend on how the criterion was originally arrived upon, nor upon what basis that criterion was originally judged to be appropriate.

The present study considers the results of a

Table 1. Some germane merits and defects of norm and criterion-based assessment schemes

Norm-based assessment schemes	Criterion-based assessment schemes
1. Pass rates are controlled—the competency of graduates cannot be independently controlled.	The competency of graduates is controlled—pass rates cannot be independently controlled.
2. Yearly variations in lecturing and/or texts do not affect pass rates, and can be difficult to notice and correct.	Yearly variations in lecturing and/or texts directly affect pass rates, and are conspicuous.
3. Scheme is unsound for small class sizes, due to a weakened statistical basis for assessment.	Suitability of scheme depends on fixed criterion selected, and is independent of class size.
4. Allows 'reliability' (result repeatability) even when 'validity' (appropriateness of assessed subject content) is weak, unjustifiable, not-considered, or absent.	Assessment is defined by content rather than result distribution, and therefore deficiencies in validity and reliability are not masked.
5. Fosters competition between students.	Promotes self-reliance among students, since the performance of other students is of no consequence.
6. Distinguishes (from peers) students who learn best under various circumstances.	Does not always distinguish (from peers) students who learn best.
7. Does not facilitate comparisons between student classes based on assessment results.	Facilitates comparisons between student classes based on assessment results.
8. Masks disparities in the standard of education between institutions.	Allows comparison of the standards of education between institutions.

solicitation of mechanical engineering staff and student opinion on assessment practice at the University of Queensland (which took the form of the second of two questionnaires described in this paper). Discussion of these results leads to the proposal of certain combination assessment schemes.

STRATEGY AND TACTICS FOR QUESTIONNAIRES

Two questionnaires, which solicited feedback on course scope and assessment issues, were given to 33 graduating students, 17 third-year students, and the academic staff of the Mechanical Engineering Department of the University of Queensland. The first questionnaire, which is relevant to engineering course scope, consists of an initial question which defines the two previously mentioned course scope options and asks the commentator to express preference between them as a number between one and five. Response to this initial question indicates commentator sentiment regarding the so-called 'breadth versus depth dichotomy' [9]. Following the initial question are four negative statements, two expressing unique perceived shortcomings of one option, and two expressing different shortcomings of the other option. The commentator is asked to communicate agreement or disagreement with each statement using a graduated scale. Finally, the questionnaire solicits written opinions on the course scope options without restrictions.

The second questionnaire, which is relevant to assessment in engineering education, begins with two questions about the effectiveness of the assessment system to which the students are now exposed. In the Mechanical Engineering Department of the University of Queensland, students are currently assessed relative to the performance of their peers, exclusively. Next, norm and criterion-based assessment schemes are defined in the questionnaire. These definitions are followed by question designed to appraise the understanding of the given definitions by the commentator. Next, the merit of criterion-based marking is questioned, with responses restricted to a graduated scale. Finally, a solicitation is made for written opinion relevant to assessment, expressed without restriction.

Staff and student interest in the questionnaires was excellent. All student questionnaires were completed, anonymously and voluntarily. Only one questionnaire was returned without lengthy written opinions. Key subjective and quantitative results of the questionnaires are reported in this paper.

RESULTS

Engineering course scope

The number of surveyed graduating engineering students who preferred a broad and shallow curriculum equaled the number who preferred a narrow and deep curriculum. This result is not surprising, since the students have little industrial experience on which to base their perception of the relative utility of the two options. Certainly in the absence of such experience, but possibly even in the presence of diverse experience, a person's choice between the options could be driven by nothing more than personality type. Several personality classification schemes exist, e.g. Myers-Briggs [10], and it is possible that the surveyed preference regarding course curriculum acted as nothing more than an indicator among equally common personality types.

However, curriculum design should depend on utility as well as popularity [6]. Perceptions of utility, though perhaps primarily influenced by personality type, can also be modified by experience or through dependence on the outcome of the decision. A regard for immediate repercussions was perhaps evident in the 3rd year student

Table 2. Basic approaches to mitigate engineering course overloading

1. Lengthen the course. Availability of resources, and the marketability of a longer course, will affect the feasibility of this option.
2. Attempt partial coverage of all topics, even if problem solving capability is not achieved in many of them. (a.k.a. 'Broad & Shallow').
3. Limit the scope of the course, such that problem-solving capability in the topics covered is assured. (a.k.a. 'Narrow & Deep'). Various metrics of worthiness can be invented to limit the scope of the course. For example, the decision of whether to include a particular subject into the course could be based on that subject's practical value to major local employers of graduates. Alternatively, the decision could be based on relevance to student-selected research assignments [11]. However, consultation with institutional accreditation bodies would rightfully influence which metric is adopted.

Table 3. Suggested hybrid approaches to mitigate engineering course overloading

1. Employ a broad and rapid coverage of most subjects, in order to reserve time and resources for a deeper coverage of certain subjects which are of a practical nature (e.g. manufacturing, design), involve fundamental principles (e.g. dynamics, viscous fluid flow, heat transfer) or provide common tools (e.g. mathematics).
2. Provide for earlier specialization through the increased use of elective subject streams. In this approach, the course for any particular student would begin as broad and superficial, perhaps for the first two years, but then finish as a thorough coverage of a narrow subject field of the student's choice. Although the course is not lengthened for any individual student, under this option, the resource implications to the institution are the similar to that of a lengthened course.

response, which advocated narrowing the curriculum (by a margin of two to one). The reason why no such bias towards narrowing the curriculum was found among the graduating students, was perhaps because such a curriculum change would have no consequence for them.

Nevertheless, both the graduating and third-year students recognized the shortcomings of the two basic approaches to cope with engineering course overloading. When asked if their confidence would suffer after graduation from a course of broad scope, due to their embellished competencies possibly outnumbering their true competencies, more than three times as many students answered in the affirmative (64%) than in the negative (20%). Furthermore, only 29% of the students believed that it would be too difficult for graduates of a course of narrow scope to adapt practiced problem-solving approaches to areas omitted from their formal education. However, when asked if their confidence would suffer after graduation from a course of narrow scope, due to fear of discussions related to topics omitted completely from their formal education, more than twice as many students answered in the affirmative (63%) than in the negative (28%).

In view of these percentages, it is not surprising that alternative or hybrid approaches to mitigate the effect of engineering course overloading were proposed by many students. Basic and hybrid approaches to mitigate engineering course overloading are tabulated in Table 2 and Table 3, respectively. The proposed hybrid approaches are arguably better than the basic approaches, and the present author advocates the second hybrid approach for his institution. This approach would be akin to 'breadth first' curriculum choices that have been made at other institutions [9].

Student performance assessment

The questionnaire concerning student performance assessment produced very clear results. Of the students questioned, 92% indicated that they had observed instances where the majority of students in a class had not achieved an acceptable level of understanding at the end of term, *and* where pass rates and grade distributions had appeared acceptable under the currently used norm-based assessment scheme. More than half of the students questioned indicated that this was 'common'. More than two thirds of the students questioned indicated that, under the currently used norm-based assessment scheme, they had observed 'many' students pass subjects without achieving a *working* understanding of the *key* material presented. These observations seem to be a severe indictment that assessment methods which are based solely on relative performance between students, are indeed incapable of consistent quality control. The widespread adoption of such an assessment practice which cannot deliver quality control, is inconsistent with the desire for quality control espoused by most educators. Similar inconsistencies in the field of education have been noted by previous authors [12, 13].

Furthermore, more than two thirds of the students questioned indicated that it would be beneficial to assess student understanding of key material in each subject against a fixed standard rather than in comparison with other students. However, many students expressed concern about how such fixed standards (against which students would be assessed in a criterion-based assessment scheme) might be chosen. It was suggested that perhaps fixed standards could be derived under the supervision of, or with input from, industry or professional engineering societies. Certainly the consequences of poorly worded or inappropriate exam questions would be more dramatic under a criterion-based assessment scheme, than under a norm-based assessment scheme. Consequently, side-effects of the use of criterion-based assessment schemes include the necessity for greater commitment to course goal communication and exam formulation by educators, and an increased visibility of shortcomings in the same. Many student commentators indicated that such side-effects were welcome and desirable, as have previous authors [14].

Table 4. Suggested combination assessment schemes

1. Norm-based assessment for large classes, criterion-based assessment for small classes.
2. Criterion-based assessment to determine *if* students pass, norm-based assessment to rank students who do pass.
3. Criterion-based assessment, but with a mixture of exam question difficulty to insure distinction of best students.
4. Criterion-based assessment for 'core' subjects, norm-based assessment for elective subjects.
5. Criterion-based assessment in first two years of course (to filter out students with low aptitude and to insure a strong foundation in the fundamentals on which to build success in subsequent years), then norm-based assessment in final years to distinguish the best students.

Many commentators suggested combination assessment schemes, which assume the characteristics of norm-based or criterion-based schemes under different circumstances. The intent of such combination assessment schemes is to employ criterion-based assessment scheme characteristics to insure a minimum competency of graduates, while also incorporating norm-based assessment scheme characteristics to counteract the year-to-year variation in lecturing and texts. Various suggested combination assessment schemes are given in Table 4.

It is a matter for further study to determine which, if any, of these proposed combination assessment schemes can meet their purported objectives. In many cases, this would depend on the nature of the implementation of the scheme (e.g. which classes are deemed large, small, core, or elective.) Nevertheless, as a consequence of the preceding discussion, and due to compatibility with the author advocated hybrid approach to course overloading, the present author advocates the final proposed combination assessment scheme for his institution.

CONCLUSIONS AND RECOMMENDATIONS

Increases in course breadth, to accommodate the growth of the field of engineering, may require corresponding sacrifices in depth of coverage for many subjects. Compromises between breadth and depth can be optimized for a particular course through hybrid approaches which can either designate subjects for broad or deep coverage, or structure the course for earlier student specialization. The former approach is more desirable from a resource perspective, whereas the latter may provide more diverse educational opportunities to the student. In this paper, the tradeoffs associated with engineering course scope, and the possible remedies to engineering course overloading, have been examined. Choices made regarding scope of the engineering course can affect, and be affected by, the methods used to assess student performance. Criterion-based assessment schemes are statistically favored by the staff and students of the Mechanical Engineering Department of the University of Queensland for listed reasons which involve discussed shortcomings of norm-based assessment schemes. Combination assessment schemes, which utilize criterion-based assessment scheme characteristics to insure a minimum competency of graduates, while also incorporating norm-based assessment scheme characteristics to counteract the year-to-year variation in lecturing and texts, are proposed.

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