Developing statistical indicators to monitor the condition of undergraduate mathematics education: a feasibility study

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Executive Summary

The teaching and learning of mathematics at the undergraduate level is currently the focus of attention by a variety of national organizations—the American Mathematical Society, the Mathematical Association of America, the Conference Board of the Mathematical Sciences, the National Academy of Sciences; and federal agencies (such as the National Science Foundation), as well as state boards of higher education.

One of the better-known reports on the condition of undergraduate science, mathematics, engineering and technology (SMET) education is *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering and Technology*. (Arlington Va, 1996, NSF 96-139). This document, commissioned in 1995 by the Directorate for Education and Human Resources of the National Science Foundation, reviews the status of undergraduate education and makes recommendations for its improvement. Among these recommendations are the following:

- **Institutions should**...
  Provide resources to ensure that faculty, particularly new faculty, have the opportunity to both learn how to and have the time to design effective instruction, use technology appropriately, foster inquiry-based and collaborative learning and assess learning achieved. (*Op cit*, p. 63)

- **Departments of Science, Mathematics, Engineering and Technology (SMET) should**...
  Provide a curriculum that engages and motivates the broadest spectrum of students, enabling every student to learn and (provide) reasonable flexibility for students to move onto or off of various career-preparation paths without undue penalty. (*Op cit*, p. 64)

- **SMET Faculty should**...
  Believe and affirm that every student can learn; recognize that different students may learn in different ways and with differing levels of ability; and create an environment in each class that both challenges and supports. (*Op cit*, p. 65)

The current project was designed to develop statistical measures (indicators) that are useful to help mathematics departments monitor the quality of education in their lower division (first two years) undergraduate mathematics program. A major goal was to devise procedures:

- To document the characteristics of mathematics programs and practices in a climate of change and
To gain experience in ways to effectively carry out a data-based self-assessment study. (e.g., what kinds of data to collect; how to go about collecting data; how to organize and report the collected data; and, finally, how to use the information gathered.)

The project is grounded in the work of a prior grant, in which a conceptual framework (see Figure 1 below) was devised for identifying and developing statistical indicators to address key aspects of program quality in lower division undergraduate mathematics. The leftmost column indicates a ‘top down’ view of the nature of undergraduate mathematics education. The rows specify levels within institutions at which mathematics programs are delivered. Systems, and their associated institutions, vary greatly with respect to missions, goals and priorities. At the department level, programs are planned, courses are staffed and taught; students are examined as to their progress in their courses; research is conducted. Indeed, the department provides much of the context within which the teaching and learning of mathematics is carried out.

The classroom level is typically where the majority of the instructional experiences that are offered. While at the student level of primary interest are attitudes toward mathematics and the levels of achievement that are attained.

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Figure 1: An Organizational Framework for the indicators project

Columns II through IV of Figure 1 map out various categories of issues that are addressed at each of the levels. Intentions (Column II) are those goals held by each of the levels (the institution, the department, and so on). The transactions that take place as those goals are realized, or put into action, are taken into account in Column III. Finally, in Column IV, the combined results of the goals and the ways in which those goals are implemented, are captured in the outcomes.

This project was carried out in three sites:
- A comprehensive state university (CU)
- A community college (CC)
- A research university (RU).

An advisory committee was formed to guide the direction of the overall study. Each of the sites also appointed its own advisory group as well. Following are the major milestones for the project:

- The following issues were identified as major themes in undergraduate mathematics education, around which quality indicators may be clustered:
  Issue 0—Departmental Demographics
  Background characteristics of instructional staff and students
  Issue 1---Department goals and priorities

1 Funded by the AERA Grants Board in 1994 and completed in 1996. The current project was funded by NSF in 1997.
Emphasis on instruction

Issue 2—Program maintenance and monitoring:
Provision for review and revision of course offerings

Issue 3—Professional development and instructional staff support
Provision for opportunities for staff development

Issue 4—Partner disciplines
Various audiences served (including teacher education)

Issue 5—Instructional strategies
Use of interactive teaching strategies

Issue 6—Classroom use of technology
Instructional applications of calculators, computer software, Internet access, etc.

Issue 7—Assessment
Use of strategies to inform the instructor about student progress rather than only for purposes of ranking students

Issue 8—Student retention
Students continuing in mathematics or mathematics-based programs

Issue 9—The mathematics department as a community of learners
Student involvement in the life of the department

Issue 10—Diversity
Representation in mathematics course enrollments of the gender, racial and socio-economic makeup of the US population

Implementation of the study:

- Survey items (upon which indicators were to be based) were developed to obtain data to address each of the three rows (levels) of the framework. This was a cooperative, consensus-building activity among the three sites.
- Preliminary versions of surveys for students, faculty and department administrators were given in fall 1997, with revisions made to the faculty survey for a second administration in spring 1998.
- The surveys were revised for final administration in fall 1998.
- Classroom artifacts (homework assignments, examinations and instructors' logbooks) were gathered at each site and were analyzed for subject matter content, representation of the content (symbolic, verbal, graphical, and numeric) and cognitive demand.
- Sixty indicators were developed, distributed among Issues 0 - 1.

Notes:
1. ‘Instructional staff’ denotes all persons who provide instruction in the department: tenured faculty; non-tenured faculty; adjuncts; part-time and teaching assistants.
2. ‘Students’ refer to those enrolled in lower division (first two years of undergraduate study) mathematics courses, unless otherwise noted.

Following are the indicators that were identified for the project, plus selected highlights, or story lines, that were gleaned from the data.
Department data

**Issue 0: Department Demographics**

**Key Indicator 0.0: Characteristics of instructional staff and student body**

0.1 Instructional staff by tenure status and gender
0.2 Instructional staff by tenure status and race/ethnicity
0.3 Student characteristics by enrollments in departmental course offerings
0.4 Student admissions policies (mathematics requirements for admission)

**Summary story lines**

The different missions of the three campuses, hence the mathematics departments, are reflected in the demographics. CU, a relatively new state university, has seven tenured faculty, mostly male, two tenure-track males and a small number of part-time staff and teaching assistants (eight in all). CC, an established community college, has 12 tenured faculty (again mostly male), 7 in tenure track (6 are males) and a large number (37) part-time instructors. RU, by contrast, has 221 individuals in teaching roles, with 66 tenured faculty (62 males). The balance consists of personnel in either tenure track, full time but not tenure eligible, part-time instructors and 134 teaching assistants (96 males). In all three departments, whites are predominant.

The size of student enrollments varies accordingly across the three campuses. In terms of admissions requirements, CC has open admissions, CU requires the basic sequence of high school mathematics, and RU, in addition to requiring the standard sequence of high school courses, makes frequent use of placement examinations to help assign students to appropriate course work.

**Issue 1: Department goals and priorities**

**Key Indicator 1.0: Departmental emphasis on undergraduate instruction**

1.1 FTE’s committed to undergraduate instruction; graduate instruction; service and research
1.2 Instructional staff by tenure status teaching lower-division courses
1.3 Instruction takes place in flexible settings
1.4 Facilities are available to enable the best possible teaching methods

**Summary story lines**

The emphasis on undergraduate teaching, as reflected in estimated allocation of instructional staff FTE’s to the standard trilogy of research, service and teaching, are again those that one would expect in terms of the missions of the respective institutions. At the community college (CC), 100% of the staff FTE is allocated to undergraduate teaching, whereas at the state comprehensive university (CU) 60% of the FTE’s are so allocated, with the remaining 40% divided equally between graduate instruction and service. At the research university (RU), the percentages are 20% for undergraduate instruction, 5% for service, 20% for graduate teaching and 50% for research. Data for the classroom indicators (Issues 5 through 8) help to fill out the picture of the emphasis accorded to undergraduate instruction at each campus.
**Issue 2: Program maintenance and monitoring**

**Key Indicator 2.0: Departmental provision for review and revision of course goals and content**

2.1 There is a written statement of department goals
2.2 A departmental syllabus exists for each course
2.3 Provisions are made in the department for the revision of courses
2.4 Course goals and content have changed within the past five years
2.5 Changes in course goals and content reflect recommendations of national reports
2.6 The department keeps abreast of the changing course needs of its students
2.7 The concerns the department has in choosing a text

**Summary story lines**

Central to the health of a department's program is the 'health' of its curriculum—for example, the extent to which the curriculum is developed, monitored and revised. Data provided by the departments indicate that all surveyed programs (lower division mathematics) had revised course goals and content and changed the textbooks for most courses within the past five years.

**Issue 3: Professional development and instructional staff support**

**Key Indicator 3.0: Departmental support of instructional staff**

3.1 The department supports and encourages the professional development of its instructional staff in the teaching and learning of mathematics
3.2 The department supports and encourages the professional development of its instructional staff in the knowledge of and ability to do mathematics
3.3 The instructional staff is using instructional technologies in the classroom
3.4 The instructional staff is using innovative instructional approaches in the classroom
3.5 The instructional staff participates in professional associations

**Summary story lines**

A concomitant measure of the 'health of a program is the extent to which the department encourages the professional development of the instructional staff. All three campuses reported that they have, in the last three years, had staff participation in professional development activities including orientation sessions for new instructors, peer observation of teaching and periodic discussion groups on current trends and issues in the teaching and learning of mathematics.

**Issue 4: Partner disciplines**

**Key Indicator 4.0: Departmental communication with partner disciplines about student needs and program content.**

4.1 The goals of the department speak to the needs and desires of a wide range of users of the mathematical sciences (that is, the ‘partner disciplines’)

**Summary story line**

A third aspect of curricular ‘health’ has to do with the extent to which the department communicates with its partners (engineering, sciences, etc) concerning programmatic goals and accomplishments. Here, the campuses vary in their ways of communicating. The community college reports being in touch with the partner disciplines at least once every five years, with the impetus for major curricular change coming from within the mathematics department itself. At the comprehensive university, meeting with partners are held once a year, with initiation of changes being a shared responsibility between the department and the partners. At the research university, engineering and the sciences generally take leadership for the mathematics courses affecting their majors, while joint efforts are usually the case for activities involving business or education departments.
Classroom

**Issue 5: Instructional strategies**

**Key Indicator 5.0: Use of interactive teaching strategies**

- 5.1 Instructors use a variety of teaching strategies
- 5.2 Instructors use a variety of interactive (non-lecture) teaching strategies
- 5.3 Instructors use strategies to promote student interaction
- 5.4 Instructors use a variety of mathematical representations while teaching
- 5.5 Instructors promote active engagement with mathematical content
- 5.6 Instructors are available to students outside of class

**Summary story lines**

While the lecture method remains the instructional approach of choice at all three sites, there are data that suggest that some instructors use other approaches, as well, such as small group work, to promote more active student participation in the class. The use of calculators in this regard, especially at the community college is noteworthy. At the research university, the use of guided discovery activities, computers and laboratory work is perhaps reflective of their use of reformed calculus programs (Harvard Project and Calculus and Mathematica).

Another source of information about the ‘climate’ of each department had to do with the availability of the instructor to students outside of class. While at each campus there was variability in the data reported by instructors, the average number of office hours per week was between 3 and 8 at each site and the average number of students assisted was between 3 and 8 per week.

**Issue 6: Classroom uses of technology**

**Key indicator 6.0: Use of technology in the classroom**

- 6.1 Classrooms are equipped for using technology in instruction
- 6.2 Courses are required by the department to use technology for instruction
- 6.3 Department provides support for technology for mathematics instruction
- 6.4 Department provides support for technology for mathematics research
- 6.5 Instructors use calculators in teaching
- 6.6 Instructor use technology (other than calculators) in teaching
- 6.7 Technology is used in teaching a variety of mathematics courses
- 6.8 The instructional workforce considers themselves proficient in using technology for teaching purposes

**Summary story lines**

Various national reports (Crossroads in Mathematics (1995); Shaping the Future (1996)) have recommended instructional applications of technology at the undergraduate level. The general sense of the data for this key indicator is that calculators are being used, especially in the community college and comprehensive state university 78% and 100% of the instructors reporting this usage, respectively). To a lesser extent, but still noteworthy, computer algebra systems (between 10% and 15% of the instructors) and other applications of computers are also found.
Issue 7: Assessment

**Key Indicator 7.0: Use of assessment methods.**

7.1 Instructors use a variety of assessment methods
7.2 Instructors seek student feedback to monitor progress
7.3 Instructors use a variety of criteria in determining final grades
7.4 Instructors assess core student proficiencies using common items

**Summary story lines**

Of the many examples of assessment listed in the survey, it is clear that by far the most commonly used methods are instructor-made exams, student homework and short quizzes. The use of more open-ended approaches for determining student achievement, such as student journals, projects or portfolios, is less common, with the interesting exception that 67% of the comprehensive state university instructors report using short projects or non-routine assignments.

Students

**Issue 8: Student retention**

**Key Indicator 8.0: Student intention to continue in the study of mathematics.**

8.1 Students feel that the instructor is aware of mathematical needs of their major field of study
8.2 Students believe that the content of the course they have just completed will be useful in their future
8.3 Students look forward to taking more mathematics
8.4 Proportionate numbers of women and ethnic minorities intend to continue in the study of mathematics.

**Summary story line**

Generally, there is a relatively positive attitude of students toward mathematics. The majority of students at each site believe that the content of their courses will be useful—with remarkable consistency of this point of view across the three campuses.

**Issue 9: The mathematics department as a community of learners**

**Key Indicator 9.0: Student participation in the life of the department**

9.1 Students take part in supplementary (non-class) mathematical support services
9.2 Students take part in supplementary (non-class) mathematical activities (e.g. lectures, colloquia, math clubs, etc.)
9.3 Students feel that technology (calculators and/or computers) is helpful in learning mathematics
9.4 Students take part in social activities of the department

**Summary story lines**

The data for this indicator are less encouraging than for most of the prior measures. Generally, students tend to not take advantage of supplementary activities or services that are available. In fact, large proportions of students report being unaware of the existence of such opportunities.
Issue 10: Diversity

**Key Indicator 10.0: Proportional representation by age, gender, and race of students in mathematics courses.**

10.1 (Lower division) student enrollment in the department shows gender diversity
10.2 (Lower division) student enrollment in the department shows racial/ethnic diversity

**Summary story lines**

The story line here is fundamentally that found elsewhere (see, for example, the NSF initiative http://www.ehr.nsf.gov/EHR/HRD/pge.asp). Mathematics instructors, at all campuses, tend to be white males. In terms of student enrollments, this pattern is not followed, since CU, the comprehensive state university, has a majority (65%) of female students enrolled in its mathematics courses. The important point here, however, is that the campus is 2/3 female, and one of their major programs is teacher education. At the other two campuses, the story is more familiar, with around 40% female enrollment in mathematics and roughly 50% female enrollment at the campus level.