From the AMS Secretary

Report of the AMS First-Year Task Force

James Lewis and Alan Tucker

Introduction

What grade has your department earned this year for that portion of its mission that is focused on teaching? More specifically, what grade would you give your department for its pursuit of excellence in teaching first-year students?

The first-year experience for collegiate mathematics instruction comprises the greatest part of the teaching and student contact for a typical mathematics department. Success with this mission thus plays a large role in the perceptions of university administrators and of students regarding mathematics, mathematicians, and their institution's mathematics department. Does your institution view your department as a pump or a filter?

First-year mathematics instruction at research universities. The AMS report, *Towards Excellence*, argues: "To ensure their institution's commitment to excellence in mathematics research, doctoral departments must pursue excellence in their instructional programs." Of special importance is the teaching and learning of mathematics in first-year mathematics courses. For many students, the only mathematics they study in college is at the freshman level. For others, the lack of success in freshman level courses serves as a barrier to mathematical-based careers in science, engineering, economics, teaching, etc. Because mathematics education plays a critical and growing role in our society, more than ever it is essential that mathematics departments pursue excellence in freshman-level mathematics.

Mathematics departments whose mission places a heavy emphasis on research and graduate education often face unique challenges in ensuring the quality of freshman mathematics instruction while maintaining the department's commitment to research and graduate education. This can be an especially difficult challenge in large state universities. According to *Towards Excellence*, public doctoral-granting departments report that over 60% of their course registrations are in first-year calculus, precalculus, or remedial courses. Combining this with some share of the instruction classified as "other undergraduate courses", i.e., courses for nonmajors, it is reasonable to estimate that over two-thirds of the mathematics instruction in these departments is at the first-year level.

Task Force charge. Concern for this issue led AMS President James Glimm to appoint the AMS Task Force on the First-Year Mathematics Experience and to charge it to:

- Identify the most significant challenges departments face as they pursue excellence in freshman mathematics instruction.
- Collect and analyze information about the diverse strategies doctoral mathematics departments are using to respond to these challenges.
- Produce a report for use by mathematics departments and university administrations with recommendations for maximizing the effectiveness of freshman mathematics instruction while maintaining their commitment to mathematics research and doctoral education.

The charge to the task force was to examine changes which can yield an improvement in such matters. Consistent with the views expressed in *Towards Excellence*, we believe that this can be done in ways that contribute to a department's research and doctoral education programs. Thus, in so far as is practical, the task force was asked to identify those steps which promise

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significant improvement while being relatively easy or practical to implement.

Factors in students' success. Of course it is very difficult to seek significant improvement in any area if one does not have a fairly clear image of what constitutes achievement at a high level. So let us pose a hypothetical question. Suppose you randomly choose a class (e.g., calculus, college algebra, etc.) that is taken largely by first-year students. Perhaps you are the instructor. Perhaps the course is taught by a colleague, a graduate student, or a lecturer hired by your institution. The students in this class have met your institution's admission requirements and have either passed a prerequisite course or have "placed" into the course based on your institution's placement test. If the instructor does a good job teaching the course, what percent of the students who start the course will complete it with a grade of C or better?

If you are anything like our friends and colleagues, you are reluctant to offer an answer to this question. You hasten to point out that "it depends." You explain that students at your university are often unprepared for the expectations of a college mathematics class, even though your institution has decided that your students meet the prerequisites for the course. You explain that many students don't come to class regularly and even those who do attend don't do enough hard work to learn the material.

To some degree, this is all true. But if this argument is presented to someone in your university administration, it will be heard as if you are arguing that the instructor is the only constant in this equation. They will interpret your comments as implying that the instructor's ability as a teacher, the energy and effort (s)he puts into teaching the course, and the pedagogical approach used to teach the class are, at most, unimportant variables. Such an argument is unlikely to be successful in an institution that is concerned with its "freshmen retention rate" or one that enters the conversation suspecting that their mathematics department devotes insufficient attention to its undergraduate teaching mission.

Low passing rates are a serious problem for departments. At a recent meeting of the AMS Committee on Education (CoE), several participants commented on their institution's "success rate", the percent of students initially enrolled in a course who complete it with a grade of C or better, in college algebra and calculus. The figure 70% was mentioned as the success rate in college algebra at several state universities, but we also heard of places where the success rate is in the mid-60s or mid-50s. At the same time, some university representatives indicated that they were criticized by their university administration because their success rate was not higher. Few parents would agree to send their children to universities if they knew the chance for success was so low and few state legislatures would willingly support a mathematics department that was producing such results. At least one person at the CoE meeting indicated that their department had a success rate in the range of 75%–80% in Calculus I. We suspect that many departments would be quite pleased if they could increase their success in calculus to this level.

We offer our congratulations to those mathematics departments that have already focused attention on first-year instruction and have achieved the significant improvement necessary to make their department an institutional showcase for excellence in teaching first-year students. We believe that many more departments will enhance their standing in their universities and be more successful at competing for university resources if they are able to achieve similar success in teaching first-year students. And, we stress that departments should seek to do this without diminishing their commitment to research and graduate education. Thus, our suggestions emphasize approaches that should be relatively easy or practical to implement but which have the potential to yield significant improvement.

Task Force focus. Taking a "first things first" approach to our pursuit of excellence in first-year instruction, we wish to advance three areas in this report that we believe merit a department's initial attention. Depending on the environment at your institution, you may choose different actions around which to focus your efforts. Our suggestions are:

- Harness the power of technology to improve teaching and learning;
- Leadership matters—success in this area depends upon the value assigned to it by a department's leadership;
- Invest in teaching graduate students to be good teachers.

Web-based Assessment and Testing Systems (WATS)

In this section, we discuss technology for faculty to help grade homework and tests. A growing number of mathematics departments are now using such technology. Historically such technology was limited to grading multi-choice answers entered as darkened spaces on a machine-readable answer sheet. A more modern example is the MAA Mathematics Placement Test software that uses Maple to check answers. One of the charges of this Task Force was to make recommendations to mathematics departments regarding this technology.

In this section we summarize a Rutgers study that makes a strong case for the value of homework software. Then we discuss the three best-known Web-based Assessment and Testing Systems (WATS) for college mathematics courses, MapleTA, WebAssign, and WeBWorK. Publishers are beginning to offer Internet-based homework grading options with some textbooks. In particular, Pearson, which owns Prentice-Hall and Addison-Wesley, is now linking many of its low-level college mathematics textbooks with MyMathLab software. Departments should ask about such options when selecting new textbooks. There are two related uses of technology in instruction that will not be discussed here. For courses below calculus, there exist a growing number of programs that provide sophisticated personalized tutoring. To allow interaction with students in a large lecture, some universities have installed small response units at each seat in a classroom with which students can respond to questions posed by the lecturer.

Overview of WATS. The new wave of WATS software accepts as responses expressions in one or more variables. These systems raise the possibility that much of the homework and tests in an introductory mathematics course might be generated and graded by such software. Tests need to be taken in supervised computer classrooms, but homework can be done on the Internet from anywhere. The most widely used mathematics WATS software is free; some of the others require students to pay most of the costs.

It is universally agreed that one learns mathematics by doing mathematics. Homework is the primary venue where students do mathematics. However, many universities lack the resources to grade student homework in large introductory courses. A fallback strategy is to assign homework but not grade it; instead, a weekly quiz on the homework will hopefully motivate students to do the homework. Homework software has the potential to handle the grading of homework at a low cost. While this software has the limitation of requiring a concise answer—an algebraic expression or a multiple-choice response—it also has an important advantage over hand grading. Namely, if a student's answer to a problem is wrong, the student learns of the mistake immediately and can be allowed to try the problem or a similar problem repeatedly until the right answer is obtained. One would expect students would try harder and put more time into their mathematics homework when they get such immediate feedback and are allowed multiple attempts. This should result in better learning. A Rutgers study, cited below, documents this effect.

In the 1970s there was considerable interest in an instructional strategy, often called the Keller Plan, where students could re-take unit tests until they demonstrated "proficiency", say, a score of 70%. The effort required to grade so many tests led to the demise of most such efforts. WATS software makes this mode of testing possible again. For example, such proficiency tests, often called "gateway" tests, can be used to check computational skills, such as the product, quotient, and chain rules in differential calculus, which students are supposed to learn largely on their own, freeing up class time to focus on concepts and applications.

A critical hurdle to the use of WATS software is the substantial effort required by faculty to learn to use it and by a department's computer experts (faculty or staff) to master the installation and maintenance of the software on a server, if the WATS is not run in a server maintained by the software provider. Because of this hurdle and because grading software is relatively new, most mathematics departments have been reluctant to be one of the pioneers to install and use such software.

With the growing use of such software, the Task Force believes that the time has come for all mathematics departments to consider adopting WATS software, especially in large first-year courses where there is often a heavy emphasis on computational skills.

Whether or not the high cost of hand grading is an issue, the immediate feedback from WATS-based homework offers important benefits over hand grading or worse, ungraded homework.

Evidence of improved learning with WATS. We will cite one study with a homework grading system that was undertaken in a calculus course at Rutgers. The situation at Rutgers, where homework had been hand graded, counting for 15% of the course grade, is typical of many freshmen calculus courses. The Rutgers study is available online (C. Weibel and L. Hirsch, 2002, "WeBWorK Effectiveness in Rutgers Calculus", `http://www.math.rutgers.edu/~weibel/webwork.html`).

Rutgers used WeBWorK, a homework-oriented WATS that randomly varies parameters in template problems to create individualized homework sets for each student. If a wrong answer is entered, students can typically re-try a problem as many times as they want up to the deadline for homework submission. In fall 2001 Rutgers's non-science calculus course with 1,300 students started using WeBWorK homework assignments in randomly selected subsets of sections that enrolled 940 students; WeBWorK sections also had several (about eight) word problems, graded by hand, each week. There were quizzes, two common mid-terms, and a common final exam. The study looked at how students' WeBWorK scores correlated with their performances on the final exam. For the purposes of the study, students in all sections were divided into three categories:

I. First-year students,

II. Other non-repeaters (sophomores or higher, taking the course for the first time),

III. Repeaters.

Given the focus of the Task Force, we shall give most attention to first-year students (group I). The average final exam score in WebWorK sections was slightly better than non-WeBWorK sections in this group, but no group showed a significant difference. However, there was a dramatic bifurcation of grades within WeBWorK sections based on how many WeBWorK exercises students attempted. It was convenient to compare the following two categories (omitting the middle 30%):

a) First-year students who scored 80% or more on the WeBWorK problems; or

b) First-year students who scored less than 50% on the WeBWorK exercises.

Most first-year students (70%) were in category a). Along with good work habits, there is also the likely interpretation for this behavior that once students got engaged in doing some of the problems, they kept on working at them. The average final exam grade in category a) was B+, while the average final exam grade in category b) was C. Remember that WeBWorK was only part—albeit the larger part—of the weekly homework assignments.

A skeptic may question the true impact of doing WeBWorK assignments: smarter students probably are in the habit of doing homework. The Rutgers study tried to account for this effect by using its precalculus-based placement exam scores which had been shown to be significantly correlated with calculus grades. This conditioning actually increased the impact of WeBWorK. For a given score on the precalculus placement exam, a student in category a) had almost a two-letter higher grade on the final exam than a student in category b): B+ versus C-.

When an analysis of variance was performed on final exam grades in WeBWorK sections, the WeBWorK homework score was the most significant predictor of performance, outweighing the placement test score, SAT scores, or high-school rank. While all these factors are mutually correlated, it is still very surprising that the WeBWorK score had higher influence on the final exam performance than measures of innate ability and high-school performance. This finding sends the heartening message that if students try hard in calculus they can do better than traditional indicators for incoming student performance would predict.

The Rutgers study found a very high probability that if a student attempted a WeBWorK problem once then the student would keep working the problem until it was correctly answered. Other studies of homework software have, not unexpectedly, found that same high probability of persistence. Also, one large survey of students found that they self-reported greater effort put into WeBWorK assignments than with hand-graded homework in similar courses (see the survey paper (V. Roth, V. Ivanchenko, and N. Record, 2007, "Evaluating Student Response in WeBWorK", *Computers and Education*, Elsevier, New York, to appear)).

In sum, this Rutgers study strongly confirms one's common sense that students get more out of homework when they get instant feedback if their answers are wrong—they work at the problems longer and they learn more in a course from this effort.

Three WATS for College Mathematics Courses

WeBWorK. WebWorK was designed to be used for homework but now has gateway test capability also. It was developed by Michael Gage and Arnold Pizer, mathematics faculty at the University of Rochester, for use in their big single-variable calculus course. WeBWorK is the only WATS that is free, with open-source code that has been refined by many users. It appears to be the most widely used WATS in calculus courses, with over 100,000 students a year. Problem banks have been developed for other courses. Several major public research universities now use WeBWorK in one of their calculus courses, including Arizona, Indiana, Michigan, Rutgers, Stony Brook, and Virginia. It has an active users group that is closely associated with the Mathematical Association of America.

As noted above, WeBWorK randomly varies constants in a set of template problems to create individualized homework sets for each student. The template problems come from problem banks that users have developed and deposited at the WeBWorK website, supplemented by problems made up by the instructor. Students can re-try an incorrectly answered problem as many times as the instructor specifies.

One of the nice aspects of WeBWorK is that an instructor can modify a problem that students are currently working on to clarify the problem's wording or give a hint. Or the instructor can add prompts for answers at intermediate stages in a multi-step problem to allow students to check that they have these intermediate steps correct. In other WATS, an instructor can create problems but no modifications are possible once students start working problems. While WeBWorK has a user interface for building homework sets, there is none for creating problems. Problems are written in PERL, which is a fairly intuitive language, so that it is possible to modify an existing problem in the ways just mentioned without knowing anything about Perl programming.

WeBWorK checks expressions entered by students by comparing their values at randomly chosen points, typically 4 points between 0 and 1, with the comparable values of the correct expressions. Thus, WeBWorK has no problem with multiple ways of expressing an answer. However, if a specified simplification of an expression is desired, as is often the case in college algebra and precalculus courses, WeBWorK cannot be used.

MapleTA. MapleTA started as eGrade, a WATS developed by John Orr of the University of Nebraska Mathematics Department to generate questions for gateway tests that students took in supervised computer labs to validate computational skills in calculus, such as standard differentiation and integration techniques. MapleTA offers two ways to randomize problems: i) randomizing parameters in template problems, like WeBWorK, or ii) randomly selecting problems from banks of individually created problems of desired types. In mode ii), if a student gets a problem wrong, (s)he normally gets another problem from the given problem bank rather than the same problem to re-try.

MapleTA permits a very powerful multi-part question which lets one create free-form questions that mix formula, number, multiple-choice, etc. elements in a longer exercise. Because Maple TA grades expressions with the Maple engine, it works well in college algebra and precalculus courses where exercises often ask students to re-write or simplify an expression. Also, Maple enables one to ask more imaginative questions along the lines of "give an example of a function that is concave upward and decreasing on [0,5]," because one can write Maple scripts to check complex criteria.

MapleTA, as the name implies, is now a product of Maplesoft, the company that sells and supports Maple, the popular mathematical software package. A department can either buy a license to run the MapleTA WATS on its own server or use a Maplesoft server, with the cost shared in the latter case by the students and the department. While MapleTA is not as widely used as WebWorK among mathematics departments, it is being used in many other scientific disciplines. The MAA Math Placement Test uses Maple. The strengths of MapleTA listed above along with MapleTA's Maple affiliation make it likely that institution-wide MapleTA adoptions may become common, making it easier and less costly for a mathematics department to use MapleTA. MapleTA has a good user interface for creating problems and building homework sets. There are a number of special features such as links with the Blackboard course administration software and a LaTeX converter.

WebAssign. WebAssign was created by faculty at North Carolina State University. A private company now owns WebAssign. Students and faculty log onto the company's servers to use WebAssign. It claims to have been used by about 800,000 students. Like WeBWorK, it is designed just for homework assignments but it has more extras like tutorials and simulations for students, and good homework record-keeping for teachers. Like MapleTA, it has good user interfaces for creating problems and building homework sets and is used in many scientific disciplines besides mathematics. Indeed, most of its users appear to be in the physical sciences. However, some major mathematics departments use it; for example, the University of Arizona and the University of Maryland use WebAssign in a range of freshman mathematics courses. Fees are paid only by the students.

The AMS has submitted a proposal to NSF to survey mathematics departments about the experience with computer homework software and, for departments not using it, about the level of interest in it.

Departmental Leadership

We are proposing here a role for departmental leadership in improving the quality of mathematics teaching. Departmental leadership is the ability to influence the culture of a department. Typically, department leaders, working with the support of senior faculty, determine the departmental culture.

Value teaching. We believe that a culture which values successful teaching will often be rewarded in tangible and intangible ways by the university administration. Conversely, a department with poor performance may suffer as a consequence. Standards for accountability are increasing across many areas of academic life. These include teaching outcomes, student performance, and student retention. We cite comments from John Marburger, the former Science Advisor to the President, that "In most institutions the engineering departments have little control over how the math and science courses are taught…there needs to be an effective stakeholder input to these service courses" (comments at the 2005 National Science Board conference, "The Engineering of 2020"). Our remarks are directed primarily toward the environment of a research teaching faculty. For this reason, we avoid suggestions which would impede the research productivity of the faculty.

Concern for teaching when hiring. The first recommendation is to pay attention to teaching ability during hiring, tenure, and promotion decisions. Usually good teaching is highly correlated with an open personality and an interest in communicating. Since we are referring to broad distinctions in teaching talent, these distinctions are usually obvious or can be readily ascertained.

Assessment of teaching. Assessment of teacher performance and student satisfaction is our second recommendation. Most universities require such assessments based on student evaluations. The question is, what to do with them? They are a useful tool if used wisely, but potentially pernicious otherwise. What constitutes wise usage? First of all, the data needs to be used sparingly, for example to identify outliers, both positive and negative, and not to make fine distinctions. Secondly, the data needs to be correlated with other, more qualitative measures of teacher performance, such as anomalies in grading practices, student drop rates compared to other classes, attendance (the fraction of enrolled students returning the questionnaire), and student complaints. Usually the outliers, both positive and negative, are more or less obvious to most department members, and the student evaluations serve to provide a measure of what may already be commonly realized.

When confirmed by other information about teaching, weak teaching evaluations can be used as a tangible basis by department leaders to talk with individual faculty about their teaching. While faculty may disparage student evaluations, junior faculty know that college tenure committees take these evaluations very seriously and tenured faculty know that university administrators take these evaluations into account when dealing with the mathematics departments on budget and hiring decisions. Thus, tenured faculty can be asked to be more sensitive to their teaching evaluations for the sake of the department's standing with the university administration.

Reward good teaching. For the excellent teachers, student evaluations, when confirmed by other information about teaching, can be the basis for rewards for good teaching. Nonfinancial rewards can be very useful, such as personal thanks from the chair or other departmental leaders; public notice, such as a list of the outstanding teachers of the semester displayed in the tea room; or announcements in faculty meetings.

In summary, a culture which values quality teaching can be nurtured by departmental leadership. If maintained consistently over time, this culture can support simple but effective methods to improve the level of student satisfaction by measurable amounts, with positive consequences for relations with the rest of the university, not to mention recruitment of students into the department's major or upper division courses.

TA Training

Forty-two years ago as a graduate student assigned to teach his first course, I (Lewis) was given a class roster and a textbook, and I was told the time and room number where the course was offered. Like many mathematics graduate students before me, and I am sure at least a few who came after me, I learned to teach on the job and on my own. There was no "TA Training" and there was no supervision of the job I did teaching that group of students. Whether this was ever acceptable is debatable, but surely it is not acceptable today. And, hopefully, it is quite rare.

There are two important reasons for a mathematics department to make it a priority to prepare graduate students to be successful teachers. First, it is in our self-interest. Many of our departments support our graduate program by employing graduate students as teaching assistants. While some departments restrict the use of teaching assistants as recitation section leaders and paper graders, there are departments where over one-third of a department's instruction is provided by graduate students who have full responsibility for their own classes. Because courses taught by graduate students are overwhelmingly at the freshman level, a much higher percentage of first-year courses are taught by graduate students. If our institution loses faith in our ability to provide quality mathematics instruction while making significant use of graduate teaching assistants, we may see a shift of instructional dollars to the use of lecturers or other teaching faculty. Without the ability to support graduate students as teachers, many of us would see our graduate program shrink significantly.

Second, it is in our graduate students' self-interest. Scan the job announcements in any issue of the *Notices* and one learns that the vast majority of academic position announcements stress the importance of the successful candidate's potential to be an outstanding teacher. Many job announcements specifically ask for a teaching statement, evidence of successful teaching experience, and indicate that one letter of reference should address teaching. Surely, we should consider efforts to help our graduate students learn to teach part of strengthening our graduate programs.

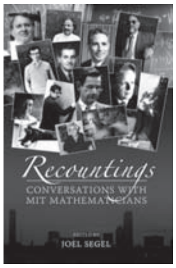
What follows is a checklist of ways that a department might invest in helping graduate students learn to teach. The suggestions are particularly appropriate for departments that make heavy use of graduate students as instructors in classes where they have complete authority.

TA orientation. Each department should offer an orientation for new teaching assistants prior to their initial teaching duties. A week-long program should offer sufficient time to introduce new graduate students to each other, the department, and to their teaching duties. This is an important opportunity for the department to communicate the importance it assigns to good performance in the classroom and to help new graduate students appreciate the need to balance their duties as a graduate student and their duties as a teaching assistant.

Super TA. Departments that use TAs to conduct recitation sections to supplement instruction offered using a large lecture format have an opportunity to use faculty lecturers to serve as teaching mentors for their recitation instructors. In addition, some departments identify an experienced and successful senior graduate student and make it part of their appointment as a TA to mentor new teaching assistants. The duties of such a position might include observing recitation sections taught by new TAs, offering feedback to the TAs, and providing feedback to the department about problems that TAs encounter but are reluctant to discuss directly with the faculty.

Careful supervision. Once graduate students are given their own class to teach, departments must make decisions as to how much independent authority the graduate student instructor should

Mathematical Reflections



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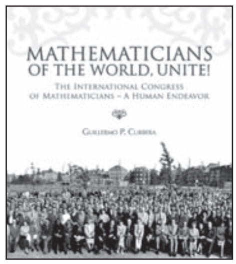

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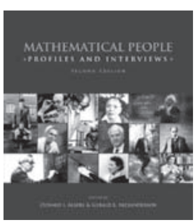

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have. Some departments report that for multisection courses, exams are written by a course coordinator and that grading is done in group grading sessions so that more experienced graders can offer advice to those less experienced. We see this as indicative of the close supervision that can help with "on the job training" and can help a department offer students consistent grading across many sections of the same course.

Teaching seminar. One way that a department can help graduate students learn to teach is to offer a teaching seminar that graduate students take the first year that they teach their own courses. The seminar might be offered for graduate credit and an outstanding teacher in the department should be assigned to teach the seminar as part of her/his teaching duties for that semester. As part of the seminar, TAs can be offered help with a wide variety of issues from classroom management to creating a syllabus and writing exams. *Teaching Mathematics in Colleges and Universities: Case Studies for Today's Classroom*, by Solomon Friedberg et. al., and *You're the Professor, What Next?*, MAA Notes #35, edited by Bettye Anne Case, are valuable resources for use in such a seminar.

Teaching mentors. TA instructors normally have a supervising faculty member, typically the person in charge of the course in which the TA teaches. Such a supervisor should serve as a general teaching mentor as well as a course coordinator. Some departments assign each TA instructor a separate teaching mentor for the first year of classroom contact. Ideally, such a teaching mentor would be a faculty member who is recognized as an outstanding teacher and who is willing to work one-on-one with a graduate student, observing her/his teaching and offering advice as the graduate student grapples with the issues that we all face as teachers.

In addition to specific steps a department can take to help graduate students develop their ability to teach, the place that quality teaching occupies in the value system of a department will contribute significantly to the energy and effort that graduate students put into their teaching. Are outstanding teachers honored by the department? Does a graduate student risk a less attractive teaching assignment, a reduction in their appointment, or even the termination of their TA appointment if they do a poor job in the classroom? By making teaching a very public activity within our department, we will contribute to a culture that values teaching and in which everyone strives to improve.