Assessment of Student Learning in College Mathematics

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FOREWORD

This volume is the second in a series sponsored by the Association for Institutional Research and aimed at assessment in the disciplines. The first year, 2005, was dedicated to employing assessment in teaching business; this volume is aimed at professionals teaching mathematics and related fields. Future volumes are planned for focusing on assessment in engineering and writing among other topics.

One might well ask, why mathematics? Mathematics is one of the most basic and important subjects taught at any and all education levels. As an example, studies that I did myself many years ago showed that success in first-year chemistry at the university level was virtually unrelated to whether or not the student had studied chemistry in high school, a counter-intuitive conclusion rejected by the distinguished chemistry faculty involved despite the hard evidence presented to them. At the same time, however, one's high school classes in mathematics, and performance in those classes, were significant predictors of performance in first-year chemistry classes at that selective university. In short, mathematics was found to be the *tool* of the science of chemistry, one that was (and remains) so important to success that it is *the* significant predictor of success. Hence the study of mathematics is critically important not only for its own sake but, even more importantly in most cases, as a very important tool of success in other disciplines.

Economic competition has led to a concern in the larger society regarding education in such fields as the sciences and engineering where mathematics has been shown to be important to success. Even in business and education, knowledge of mathematics and its sister field of statistics, which is based on mathematics, is critically important to success. As a consequence, it is important to us as a society to do the best that we can to ensure that our students are getting the highest quality education possible in this most important field.

This volume is exciting because it is about how to convey one's enthusiasm about an interesting field of study even when teaching at relatively basic levels. The authors of the chapters, and in particular the editor, Bernie Madison, deserve a lot of thanks for producing fascinating insights about teaching a subject which they clearly love and how assessment can enhance that teaching. To me that is the very definition of a faculty member, *i.e.*, one who conveys the love of the subject matter in an understandable fashion. Using this definition, the volume which follows is the product of some loving sharing by very capable faculty members.

I would also like to convey a special thanks to the Association for Institutional Research, and especially the Publications Committee and the current editor of the *Resources in Institutional Research* series Rich Howard, for sponsoring this series. We in institutional research cherish our role as partners with faculty in improving higher education through assessment. This volume and series are tangible evidence of that commitment.

John A. Muffo
Ohio Board of Regents

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CHAPTER 1. INTRODUCTION TO THE VOLUME ASSESSMENT IN COLLEGE MATHEMATICS: MANY OPTIONS

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Introduction

The vast and varied landscape of collegiate mathematics has enormous inertia, built over a century of experience with a fairly stable offering of courses. In recent years, however, mostly during the last quarter century, innovations and reforms have overcome some of the inertia. Assessment of student learning, especially in programs or in coherent blocks of courses, is playing a major role in some of the reforms by providing evidence of improvements, identifying changes that need to be made for more improvements, or validating existing practice. Assessment is prominent in U.S. collegiate mathematics largely because it has been mandated by entities external to the mathematics faculties, but the value of assessment done right is becoming more apparent as mathematics faculties take ownership and work seriously toward improved courses and programs.

This volume presents a remarkably descriptive sample of assessment activity across U.S. mathematics in 10 case studies from nine institutions. An additional metaphorical essay gives the flavor of assessment's interaction with U.S. collegiate mathematics. The size of U.S. collegiate mathematics —over 3,000 institutions with mathematics programs—makes any comprehensive description of assessment activity untenable. However, this volume, when coupled with two previous volumes of case studies by the Mathematical Association of America (MAA) (See Box 1 and Box 2), provides a diverse and informative survey of assessment programs in collegiate mathematics (Gold, Keith, & Marion, 1999; Steen, 2006). Two features distinguish this volume from the previous MAA volumes: The case studies here are more extensive and detailed, and the assessment programs being described are more mature. The format for these case studies was free form with individual authors deciding what to report and how to report it. Nonetheless, there are common themes throughout, with the most common and overriding theme being the quest for improved courses and programs based on evidence of student learning.

Assessment of student learning across multiple courses is alien to the world of many college mathematics faculty. Circumstances in collegiate mathematics mitigate against faculty initiatives for substantial assessment programs (Madison, 2006). Yet most mathematics departments have responded to mandated assessments, and some of those have proven effective and positively productive. Two of the cases in this volume—Keene

State College (KSC, Chapter 4) and Nassau Community College (NCC, Chapter 3)—not only provide good examples of productive responses to mandates but also contain good advice for others to follow. One of the cases—Alverno College mathematics (Alverno-Math, Chapter 5)—has a subtext of a new mathematics faculty member adapting to a culture of assessment that had developed at Alverno over the previous 10–15 years. Alverno College is often cited as a model of a culture of assessment, having been engaged in a college-wide effort for three decades.

Some of the cases began and continue the quest for improvements outside the pure assessment of learning movement, measuring course effectiveness by grades, student opinions, and student retention. In all such cases, more direct measures of student performances to demonstrate learning have been or are being adopted, moving closer to the now widely accepted model of assessment for the purpose of program improvement.

Box 1
Assessment Practices in Undergraduate Mathematics

This 1999 volume contains 72 brief case studies collected during the period 1996-1998 that describe assessment activities at a wide variety of colleges and universities. Techniques offered in this book range from brief ten-minute classroom exercises and examples of alternative testing, group work and assignments, to examples of how departments may measure the placement of students into courses, the effectiveness of the major, and the quantitative literacy of their graduating students.

Bonnie Gold, Sandra Z. Keith, and William A. Marion, Editors

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Numerous and Varied Motivations

The reasons for seeking course and program improvements and for the wide variety of methods illustrated in these ten chapters are numerous and compelling. These reasons explain both why certain practices are followed in assessment and why assessment is complicated and restrained. Among the reasons are the following circumstances in U.S. collegiate mathematics over the past three or four decades.

- *Increasing enrollments*. Enrollments in U.S. collegiate mathematics

Box 2
Supporting Assessment in Undergraduate Mathematics

This 2006 volume contains 26 case studies offering lessons learned during a four year National Science Foundation (NSF) - supported MAA project designed to support mathematicians and mathematics departments in the increasingly important challenge of assessing student learning. Three introductory essays (by Peter Ewell, Bernard L. Madison, and Lynn Arthur Steen) set assessment in broader academic and national contexts. Case studies deal primarily with coherent blocks of courses designed for particular purposes, (*e.g.*, general education, mathematics-intensive majors, developmental education, quantitative literacy, teacher preparation, and mathematics majors). Institutions represented in the volume vary considerably in size, location, and mission.

Lynn Arthur Steen, Editor
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more than doubled in the period 1960–1990 to approximately six million per year, placing strains on departmental faculties to respond appropriately (see Figure 1). This is a major issue in several of the case studies, especially those from University of Arizona (Arizona, Chapter 11), Colorado School of Mines (CSM, Chapter 9), University of Texas at El Paso (UTEP, Chapter 10), and Virginia Commonwealth University (VCU, Chapter 6).

- *High unsuccessful rates.* Collegiate mathematics provides major challenges for many students, and unsuccessful (failure or withdrawal) rates are high at many institutions, where sometimes more than half the students in introductory courses fall into the unsuccessful category. Most institutions, especially those with large enrollments, have been seeking improvements. This has led to innovative approaches to course structures, more rigorous admission and placement processes,

changes in class sizes, tutoring programs, and many other efforts. Two of the case studies in this volume—Arizona and UTEP—provide excellent examples of responses to this issue.

- *Growing and changing demands for service courses*. Most college mathematics enrollments result from course requirements for other college majors—notably, sciences, engineering, and business. The need for mathematics in these disciplines has grown and changed over the years. Almost all the cases in this volume address this issue, but four of them have it as a major theme. One of the four, relating experience at North Dakota State University and University of Wisconsin-Madison (NDSU, Chapter 2), focuses almost entirely on service courses for other disciplines. Another, from the United States Military Academy (USMA, Chapter 8), illustrates how a core mathematics program serves every undergraduate major. Two others highlight issues with engineering (CSM) or business (Arizona).

- *Articulation with K-12, including the need for remediation*. As college enrollments increased in the 1960s and 1970s, remedial or developmental mathematics courses became more numerous in colleges, especially in two-year colleges. These courses, whose content is largely arithmetic or beginning algebra, do not usually carry college degree credit yet constitute approximately one in three enrollments in college mathematics (Lutzer, Maxwell & Rodi, 2002). These and related circumstances have prompted closer coordination or articulation between K-12 mathematics and college mathematics (Madison, 2003). Two of the cases here, Arizona and NCC, address this specifically.

- *More variety of students*. As the graphs in Figure 1 and Figure 2 show, during 1950–1990, college attendance became the norm in U.S. education. This vastly increased college population, from both larger percentages of new high school graduates and returning older students, increased the variety of students who represented various learning styles and goals in college mathematics. These changes prompted the need for new courses and assessment methods as illustrated in the Alverno cases and the VCU case.

- *Need for general education courses.* Until recently, many mathematics departments' offerings were of two kinds: courses for mathematics majors and service courses for other disciplines. Students who wanted mathematics for general education usually enrolled in courses designed as service courses, but this has changed in recent years. The growing quantification of society has prompted the design of courses for general education, often under the rubric of quantitative literacy (QL). Two of

the cases, VCU and Alverno College, quantitative literacy (Alverno-QL, Chapter 7) highlight how two institutions are teaching and assessing QL.

- *Growing demands for accountability*. Demands for accountability of learning productivity in higher education have been growing for 25 years. Some of these demands come from within institutions (*e.g.*, Alverno and USMA) while others come from external entities such as systems (*e.g.*, NCC) or the state (*e.g.*, KSC and Arizona). These demands for accountability are largely responsible for the prominence of assessment in collegiate mathematics. During the past 25 years calculator and computer technologies have dramatically changed the way mathematics is practiced in applications. The ready availability of powerful hand-held calculators was a major factor in promoting calculus reform in the 1990s and continues to provide impetus for investigating how to best utilize this technology in collegiate mathematics teaching and learning. Assessing learning in the presence of technology is a major component of the USMA case, and the KSC case highlights how assessment can point to weakness in students' capabilities with technology.

- *More awareness of responding in practice to learning research results.* Research on learning in mathematics has had little effect on practices in collegiate mathematics instruction. This is due in part to how little we know about how students develop mathematical capabilities and mentally construct mathematical concepts. Nonetheless, as faculties attempt to measure student learning developmentally, knowing how this learning develops becomes critically important. Aspects of this development are present in most of the cases, but more prominent in the more mature programs such as the two cases at Alverno (Alverno-QL and Alverno-Math) and at USMA.

Evolution of U.S. Collegiate Mathematics

To understand better the current environment of assessment in U.S. collegiate mathematics, it helps to consider five time periods: before 1920, 1920–1950, 1950–1975, 1975–1990, and after 1990. Before 1920, most U.S. colleges offered a classical curriculum with all students studying the same subjects during the four years. Comprehensive assessment, often using external readers, was common practice. A significant portion of the college curriculum was classical mathematics: plane, solid, and analytical geometry; plane and spherical trigonometry; and algebra. With the reform of the Harvard undergraduate curriculum led by Harvard President Charles Eliot during the latter part of the nineteenth century, majors and electives were introduced into U.S. higher education. As a response to this change,

general education courses were introduced to complement the study-in-depth in the major (Steen, 2004).

***Majors and electives*.** The second period roughly spans 1920–1950. During this period, collegiate mathematics offerings for non-mathematics majors were very similar to those of the classical curriculum. In fact, mathematics was essentially alone as a mainline academic discipline in not developing general education or introductory college courses. There were, however, during this period various efforts to create mathematics courses for the liberal arts. See, for example, the description by Allendorfer (1947).

Expansion

For several reasons, following World War II, U.S. mathematics expanded, a circumstance that dominated during 1950–1975. The National Science Foundation (NSF) was established in 1950. Federal programs such as the GI Bill following World War II and the National Defense Education Act enacted in 1958 following the launch of Sputnik by the Soviet Union encouraged and supported science and mathematics study in college. Applications of mathematics during the war had elevated the importance of mathematics as a practical subject in an industrial society. In addition, several non-governmental movements and developments pushed college mathematics forward. In the 1940s and 1950s the School Mathematics Study Group's development of the "new math" began, use of the College Board's SAT examination expanded, the Advanced Placement program was created, and Educational Testing Service (ETS) and American College Testing (ACT) were founded.

Mathematics study expanded because of an emphasis on mathematics-intensive majors and the increased college-going rate among U.S. students. Comprehensive assessment became unwieldy and course grades became the dominant assessment measure. As Figure 1 shows, during the 15 years 1965–1980, the number of enrollments in the fall term in college mathematics courses (two-year and four-year colleges) increased by 90%, from approximately 1.35 million to 2.57 million, leveling out at about 3 million in 1990. Since the fall term is approximately half the total annual enrollment, currently there are approximately 6 million enrollments in college mathematics courses every year (Madison & Hart, 1990: Lutzer, Maxwell, & Rodi, 2002).

This increase was analogous to the increase in the total U.S. college enrollments, which more than doubled over the period 1965–1980 from 5.3 million to 11.6 million, creating a greater variety of students, both in educational background and interests. See Figures 2 and 3 that are graphs of data from the U.S. Department of Education (Snyder, 1993).

During the period 1950–1975, mathematics departments in colleges and universities were dealing with increasing enrollments in both their undergraduate and graduate programs, some increases in courses for