Changes in College Algebra

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Abstract

The high rate of students' failure in the college algebra course could be a problem of admissions, placement, curriculum design, or instruction. This paper focuses on the curriculum in light of the needs of the students who tend to enroll in the course. The traditional college algebra curriculum is contrasted with the alternative curricula developed in recent years by textbook authors. Related issues of national and local educational policy are also discussed.

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Introduction

The high rate of students' failure in the college algebra course could be a problem originating in admissions policy, placement activities, curriculum design, or instruction. This paper focuses on the curriculum as a partial solution to this problem in light of the needs of the types of students who tend to enroll in the course.

The traditional college algebra curriculum seems to assume that the course is a preparation for calculus. But surveys at many institutions have shown that only a minority of College Algebra students go on to take calculus of any kind, and only a small fraction of those attempt a full-year calculus sequence. Thus, in recent years textbook authors have developed alternative curricula that address the future mathematical needs of the soft-sciences students. We contrast these curricula with the traditional College Algebra course and identify the related issues of national and local educational policy.

The DWF Problem

The 1997 MAA panel discussion on College Algebra Reform had one participant who was certainly an unusual guest at such meetings. He was a university president, and not himself a mathematician. Raymond Hicks of Grambling State University told the audience of his administration's concern about the high failure rate of College Algebra students. It is not only bad public relations for the math department, he reminded the attendees, but it is demoralizing to the students.

The College Algebra course has a reputation nationally for failing an unusually high percentage of students. The percentage of students who earn D, W or F grades—the DWF rate—may be 30–40% on average across colleges, and some report that it is as high as 90%. A study conducted for a two-year institution in Georgia found DWF rates of 25–31% for the freshman courses in English composition, psychology and government but 47% among the 4,400 students in the math modeling course that takes the place of college algebra there, despite the fact that the distributions of mathematical requirements implied by the majors declared by students in these three freshman courses were nearly identical.

In business and industry, a product defect rate of 40–50% would quickly cause some vice-president to lose his or her job, but the DWF problem of the college algebra course has persisted in American higher education. As President Hicks told his audience at the MAA meetings, this problem demands a solution.

The solution will be located at one or more of the stages of the educational process. It could be a problem of **placement**, especially at institutions that do not use placement tests. But it can also be a problem at schools that use either high-school exit exams or standardized college placement tests that do not mesh well with the local curriculum. Furthermore, many students want to get out of the requirement to take college algebra, so there can be a problem at schools whose computer systems cannot enforce prerequisites or block prohibited requests to change a registration. The placement issue is more serious at schools whose admission is open or nearly so. An open admissions policy can promote a general attitude among the faculty and administration that all students deserve the right to try but that not many are really suited to succeed. Thus, the institution may pretend that failure is the fault of the student.

The DWF problem may also have its origin in **curriculum design**. Some College Algebra courses are designed as precalculus on the assumption that most if not all students will need to take calculus for their majors. At such an institution, if the course is attended by students headed toward majors that do not require calculus, there will probably be a higher failure rate among the students of the less mathematically intensive majors. A two-year college in Georgia found this in a study of the DWF rate among students of various majors who were taking College Algebra. The overall DWF rate was 49% among more than 2,300 students, and the largest groups (business, education, and undeclared) had DWF rates very close to this average, but the 108 majors in communication arts had a DWF rate of 59%, and though there were smaller groups in other majors, students had DWF rates in excess of 60% from sports management, English, building construction, interior design, hotel administration, sociology, child development, and recreation.

Even a well-designed curriculum suited to the composition of the class can be poorly implemented by the instructor, so **instruction** is one possible cause, especially at schools that hire current or former high school teachers as College Algebra instructors. The College Algebra course *should not* be just a louder version of high school algebra (Pollack, 1997, p. 89). It is significant that in the study of East Georgia College students, the one group of students in the college algebra class that had far and away the lowest DWF rate (17%) was that of high school students taking the course for college credit. The typical student takes College Algebra in college precisely because he or she did poorly in Algebra II in high school. Typically across the U.S., this student will be motivated by examples from business, health sciences, social sciences, and education, but less so by the examples from the sciences or the contrived examples from personal life that tend to appear in high school texts. As a footnote to the problem of instruction, we should remind ourselves that assessment is a closely related issue. If our examinations do not mesh with the course's content, its type of applications, and its level of abstraction, then students may still appear to do poorly.

Placement is likely to be a major contributor to the problem, but its solution centers greatly on an institution coming to grips with its own mission and defining its responsibility to students.

We may hope that instruction is not the core of the problem, though faculty development certainly deserves attention at all institutions. In this paper, we focus on the curriculum as the center of attention in reforming or renewing the College Algebra course. The basic principle of curriculum design is that the curriculum should be suited to the needs of the student, so we now consider the types of students who take College Algebra.

Who Takes College Algebra?

Dunbar and Herriott (2001) cite data on the intended majors of College Algebra students at the University of Nebraska at Lincoln and at ten colleges and universities in Illinois. It is not unusual for an institution to have 40% of its College Algebra students headed toward a business major, and at urban locations it may be over 50%. Students from the life and allied health sciences tend to comprise 20% of the class, and those in the social sciences about 15%. Education and humanities majors may be another 10%, and the remaining 10–15% will be planning a major in the hard sciences or in computer science.

Thus, the vast majority of students in College Algebra are headed toward the managerial, social or life/health sciences. It is these subjects whose mathematical requirements should guide the curriculum for College Algebra.

Curricular Models for College Algebra

The curricula taught under the name College Algebra can be dramatically different at different institutions, yet overall there is a fairly consistent pattern in the type of student who takes the course. Many of the students have not fared well in prior mathematics courses and have a fear of mathematics.

In this section, we attempt to describe several distinct models for a College Algebra course, as expressed in the content, organization, and pedagogy of textbooks. In doing so, we tend to emphasize the extreme examples of each type. Certainly, there are curricular models that mix elements of these, but characterizing the extremes helps us understand the choices that the curriculum designers have made.

The essence of a college algebra course is the solution of equations—as one would expect of a field in which the Fundamental Theorem concerns the existence of a solution to an important class of equations.

"Traditional" College Algebra

Purpose and Clientele

The traditional college algebra textbook covers the key concepts of high school algebra in the context of studying functions and their graphs. This context and the selection of functional forms and other topics for coverage is designed to prepare the student for calculus. Indeed, the preparation for calculus may well be a guiding feature of this curriculum. As Sobel and Lerner (1995, page AIE v.) point out in their introduction to the instructor's annotated edition,"Since calculus is a subject numerous students study after this course, special emphasis is given to the preparation for the study of calculus. Thus, one of the *major objectives* of this book is *to help the student make a comfortable transition from elementary mathematics to calculus*." [italics in original]. The example of Sullivan and Sullivan (1996, p. xii) shows that not all traditional texts make that assumption, but the content of these texts still reflects it.

Other examples of textbooks along this model are Larson and Hostetler (1997), Lial, Hornsby and Schneider (1997), Ruud and Shell (1997), and Bittinger et al. (1997), Cohen (1996), Sullivan and Sullivan (1996), and Dugopolski (1995), Stewart, Redlin and Watson (1996).

Content

The course covers the analysis of linear, polynomial, exponential and logarithmic, radical, and rational functions through the study of their graphs and the methods of solving their corresponding equations. Systems of equations are solved by matrix inversion. Systems of linear inequalities are studied as a context for linear programming problems, which are solved by the graphical method. Sequences are covered near the end of the course as a way to introduce the concept of limit. The text often includes a unit on conic sections, and it may include a chapter on elementary probability theory.

The solution of polynomial equations is based on the concept of factorization. The study of rational expressions frequently includes partial fraction decomposition, which is necessary in calculus for the integration of rational expressions. The complex number system is likely to be discussed in the context of solving polynomial equations. Systems of linear equations are solved first by substitution and then by matrix methods.

Organization

The first thing a student sees when opening the textbook, on the inside cover, is a page or two of equations in small type with lots of exponents and parentheses. In addition to serving as a handy reference, this probably brings back memories of the student's high school algebra experience. Those memories are reinforced in the first chapter, which as often as not is given the demeaning label Chapter R rather than Chapter 1, where the student receives a quick review of the properties of the real number system, exponential notation, operations on polynomials, factorization of polynomials, and rational and radical equations, and perhaps complex numbers as a way to get started in the course.

The first substantive part of the text is usually a pair of chapters dealing with functions and graphs and with linear and nonlinear equations, in either order. Following those in fairly consistent order are chapters on polynomial and rational functions, exponential functions, systems of equations and matrices, conic sections, sequences and series, and sometimes finishing with permutations and combinations or probability.

Pedagogy

Applications may appear in the text to motivate the student's interest, but the vast majority of the homework exercises concern symbolic manipulation, not the formulation of an equation. Thus, problem solving and critical thinking skills are not emphasized, nor are communication skills.

The applications tend to be drawn from the hard sciences or geometry rather than the soft sciences. Interdisciplinary applications are limited, and applications tend to be shallow and quick. One textbook listed a problem concerning the sum of the digits in the year that the transcontinental railroad was completed as an application in the field of "transportation."

The curriculum teaches students to work with functions under their numerical, graphical and symbolic representations, the Rule of Three, but it does not emphasize the verbal representation of functional relationships nor the process of modeling functions from written descriptions.

Pedagogy tends to emphasize the traditional lecture and makes little use of technology.

College Algebra With Trigonometry

This curriculum is the traditional college algebra course together with the study of trigonometric functions (cf. Aufman, Barker, Nation, 1997). Many textbooks teach precisely this curriculum under the title "precalculus." Including the trig, this course is clearly designed as a preparation for calculus. Its review of high school algebra and of the traditional college algebra's functions and graphs is accelerated in order to fit in the trigonometry.

An unpublished study at the University of Nebraska at Lincoln found that of all the students who enrolled in College Algebra and Trigonometry in 1993-94, 59% of them took Calculus I within the next five semesters. Only 5% of the students in this college algebra course took the "soft" calculus course for business and the social sciences. These data show that the College Algebra with Trigonometry course is genuinely pre-calculus.

Models of "Reformed" College Algebra

Purpose and Clientele

Efforts at reforming the college algebra course in the last 5–10 years have the same spirit as the earlier movement to reform the teaching of calculus.

- The DWF rates indicate a serious problem. They show that the course is not fulfilling an educational purpose.
- The course has been used as a filter, when it should be used as a pump.

A tenet of the reform movement is that the course should be designed to serve the needs of the students who take it, so mathematics faculty must understand which other departments in their university or in their transfer schools expect the students to have taken this course. And they must understand specifically which aspects of College Algebra are used in the various majors that require it.

College Algebra is frequently required of students who major in business, the social sciences, biology and health sciences, and education. Many state licensing boards require nurses to take College Algebra. The students who take algebra at college typically did poorly in the subject in high school, or as adults have not seen the subject for many years, and the content and organization of the reformed College Algebra curriculum is designed for these students.

Content

The curricular themes of college algebra reform are expressed well in the AMATYC *Crossroads* report (Cohen, 1995). The main goals for **intellectual development** concern transferable problem-solving skills such as exploration, modeling, inductive and deductive reasoning, and tenacity as well as technical skills of a general nature such as communication and the use of technology. In **content**, the theme of reform is that "problem solving is the heart of doing mathematics" and that students gain the power to solve *meaningful* problems through in-depth study of specific mathematical topics. But depth does not necessarily refer to theoretical depth, such as study of the complex number system along with quadratic equations. It can mean an extensive exposure to a range of applications of a single functional form, so the student learns to see the pattern that identifies a linear relationship, an exponential relationship, and so on.

The orientation toward meaningful applications is a key theme in the content of the reformed curriculum. In the Algebra Initiative Colloquium, Davis (1995, p. 160) commented, "One could argue that no concept of algebra should be taught unless it can be motivated by a problem that is likely to be part of the students' experience in the near future." Many topics in the traditional curriculum would have a difficulty passing this test.

The concept of function is essential to modeling relationships among real world phenomena. Reform emphasizes the Rule of Four—understanding functions verbally, numerically, graphically, and symbolically—along with the ability to transform functional relationship from one representation to another, which is the essence of mathematical modeling. However, for example, it is possible to define a function contextually, as a relationship between variables *x* and *y*, rather than abstractly as a rule of transformation *f*.

The emphasis on ideas in context, rather than ideas in the abstract, seems to characterize the main efforts at reform. In the Algebra Initiative Colloquium, Artin (1995, p. 72) commented,

> For an undergraduate course, the most important thing the students should come out with is a familiarity with some examples—some basic structures on which they can build their understanding. That is more important than theory.
>
> We should be ruthless in asking: 'Is it important for the average student in the class to learn this material?' If not, throw it out.

Given that the average community college student is 27 years old, Pollack (1995) had a particularly salient observation, "An algebra experience centered around the usefulness of the subject may succeed where previous attempts at rote learning did not, especially with an older student."

Davis, Artin and Pollack all reinforce the notion that the design of the College Algebra curriculum should reflect a keen understanding of who the student is and what their needs are. In the reformed curriculum, topics should be evaluated according to their future usefulness to the student and for the transferable skills that their study provides.

Organization

When opening the textbook of a reformed course, on the inside cover the student sees a page or two listing the areas of application of the material covered in the book, not a mass of equations in small type with exponents and parentheses. This sends a signal to the student that the textbook will have practical value.

From the reformed perspective, the traditional textbook's initial Chapter R (named without even the dignity of a chapter number) that covers equations, exponents, factoring, rational and radical expressions, and complex numbers as a "review" is a sure formula to instill mathematics shock in the typical College Algebra student. In contrast, the first part of the reformed curriculum recognizes that the College Algebra student may have been out of school for a while or did poorly with algebra in the last encounter. The initial reformed chapter covers linear functions through the study of linear equations and their graphs, in various forms corresponding to the various natural language descriptions of linear relationships. Significantly, systems of linear equations and inequalities follows this *immediately*. Linear systems are likely to be solved by substitution and Gaussian elimination but not by matrix methods. Matrix algebra, in the reformed view, belongs in a linear algebra course.

Following the study of linear functions, the reformed curriculum treats exponential functions, not polynomials. There are several reasons for this organization of the curriculum, centering on the ease of transition from linear exponential functions. These functions each have two parameters, one of which is the vertical intercept. They each describe growth or decline though in different ways. And the solution of an exponential equation by logarithms results in a linear equation that the student knows how to solve. Exponential equations may be studied in depth through applications of the various forms (standard, base two and natural base) that correspond to the various natural language descriptions of exponential relationships. Variations on the exponential theme may include vertical shifts (Newton's model of heating and cooling) and the reciprocal of that, the logistic function.

Following the study of exponential relationships comes polynomial functions, with emphasis on the quadratic. Complex numbers are typically introduced in a limited manner. Factorization is treated as a property of the polynomial but not given much emphasis as a solution procedure for polynomial equations. The curriculum may emphasize the formulation of quadratic equations from real-world descriptions or from graphs or tables of data. The solution of the equation by the quadratic formula is treated as a useful, generic technique.

Sequences, arithmetic and geometric, may appear optionally in the curriculum through the study of the general first-order difference equation, which subsumes linear and exponential functions defined over the whole numbers and thereby helps integrate the curriculum (Gordon et al., 1997; Kalman, 1997; Small, 2001).

Pedagogy

The reformed curriculum of college algebra tends to treat the *formulation* of an equation as an intellectual skill no less important than the *solution* of the equation. That is a significant departure from the traditional curriculum. Faculty schooled in the traditional curriculum probably reply, "That's not algebra. Algebra is about the solution of equations." True enough, but the purpose of the curriculum is to do more than teach algebra. The AMATYC *Crossroads* report describes a broad range of intellectual skills that should be developed in the subcalculus curriculum. The solution of equations only one step in the more general objective of *problem solving*. Kenschaft (2000) reports the experience of a mathematics alum who wrote in a survey, **"**Business is one 'word problem' after another**."** The task of taking a verbal representation and formulating it symbolically is an intellectual skill of high order and one that students will need in their careers. But it is harder to teach than the manipulation of algebraic expressions. It

A consistent pedagogical theme in the reformed courses is this transformation of one representation in to another. Transforming a verbal, numerical, graphical or symbolic representation of a relationship between variables into one of the other forms is the essence of mathematical modeling. Some curricula, such as Herriott (2002) place relatively more emphasis on the verbal-to-symbolic transformation, reading a description and writing an equation. Others such as Gordon et al. (1997), Kime and Clark (1997), and Crauder, Evans and Noell (1999) and Small (2001) give special attention to the numerical-to-symbolic transformation, fitting equations to data. Rockswold, Hornsby and Lial (1999) introduce this idea in their adaptation of a traditional curricular organization.

The mere use of technology does not tend to distinguish a reformed from the traditional curriculum, because even traditional courses are using graphing calculators. But the reformed courses tend to use technology, including spreadsheet software, more intensively with applications.

Does reformed College Algebra still prepare students for calculus?

It is often said, "Student's don't fail at the calculus. They fail at the algebra." It is a reasonable guess that about 10% of the College Algebra students nationally will go on to attempt the first semester of a year-long calculus sequence, and about 35% will take a one-semester course in calculus for the social, managerial and life sciences. The qualities that students needs to succeed in either of these courses are an understanding of functions and graphs, the ability to solve equations, and confidence in their ability to learn math. The reformed curricula tend to give a thorough graphical treatment of functions, including a discussion of end behavior and turning points. They give plenty of practice in solving equations. And their content and organization are designed to encourage the student's confidence in the ability to work with abstractions. It is a reasonable guess that such students will be equally prepared to succeed in a calculus course that emphasizes applications in business. But so students who attempt the full-year calculus sequence will need trigonometry, which is not usually in the reformed algebra curricula.

College Algebra as a General Education Course

In states such as Texas, Louisiana, and Georgia, College Algebra or a near substitute is required of all students as general education. There may not be a single curricular design that serves well the future needs of the English and fine arts majors and those in the managerial, social and life/health sciences. Thus, adaptations of the College Algebra curriculum to suit a general education objective tend to be radical departures from the traditional curriculum.

Small (2001) developed his *Contemporary College Algebra* explicitly for those institutions where College Algebra has the broader objective of developing quantitative literacy. Topics in his curriculum include the display and interpretation of data, linear equations and inequalities, and linear programming (graphical). Functions are studied in all four representations, and modifications of a collection of elementary functions (linear, exponential, power, quadratic) are obtained using shifts and rescalings and using the algebra of functions. Through case studies of applied problems students learn the skill of modeling, and they develop confidence as a problem solvers in meaningful situations. Technology enhances the study of data and graphs, and small group work and written assignments develop communication skills. As one example, the distance it takes a vehicle to stop from various initial speeds is presented first as data in a table from a State Driving manual. Students plot the data and fit a curve to the data plot. The resulting function is used to extend the data in the Driver's Manual.

Small group projects can be an important element of the College Algebra pedagogy. These projects involve an inquiry aspect that involves students in real life activities such as pricing materials in a store, writing a business letter, interviewing a bank official, conducting a survey, and searching the Internet. Projects conclude with a written report that involves group reflections. The present thinking in the business world places a high priority on group work, so these projects develop workplace readiness.

At other institutions, the general education curriculum includes a wider range of subjects studied less deeply including the real number system, graphing and solving linear equations, geometric calculations, elementary probability and statistics, and consumer mathematics.

Local and National Policy Issues

This survey of changes in the College Algebra curriculum raises several issues that mathematics faculty must resolve at each college and university, and it poses a few questions that should be considered in national policy making.

Algebra as Mathematicians Know It vs. Algebra as Graduates Use It

It should be easy to argue that the content of the Fundamental Theorem in any branch of mathematics belongs in the college-level curriculum of the subject. For College Algebra, this would suggest that the study of polynomials should get the main billing in the course, and indeed it does in the traditional curriculum. But algebra *as mathematicians know it* is not necessarily the algebra that college graduates (of all majors) will need and that they should learn in college. It is very difficult for a devoted mathematician to abandon the most beautiful ideas of his or her field and teach a “watered down” curriculum to students from across campus. That is why topics such as partial-fraction decompositions, complex numbers, the algebra of functions, and inverse matrices find their way into the textbooks and why words such as *group* and *field* can slip from the lips of the faculty teaching this course. The desire to share the extraordinary beauty of higher mathematics comes from deep in the heart of the mathematician.

That is why it takes some work to keep a focus on the goal of helping the student up the next step of their own career path. Examples may in fact be more important than theory. And it may be more important for the student to come out of the College Algebra course knowing how to fit verbal descriptions to a variety of forms of the linear equation. And it may be more important to have a good facility with exponential functions than a knowledge of polynomials. It may be more important to understand a multivariate linear function than to understand a univariate rational expression.

Every mathematics department should develop a clear sense of which academic departments they are serving through the College Algebra course and which topics their students will need to understand and what skills they will need to have.

Admission and Placement vs. Instruction and Assessment

If College Algebra has been used deliberately as a filter, then it may be timely to reconsider the assumptions of that policy, especially at public institutions. Restrictive admissions policies may be politically difficult for some state institutions to defend, and failing grades may seem to be a more objective way to discriminate between those students who deserve higher education and those who do not. But the implicit contract that an open admissions policy creates between the student and the institution is much more ambiguous than the restricted admissions policy of an institution which defines its clientele clearly, admits according to standards appropriate to that clientele, and allocates resources to whatever educational functions are necessary to support the success of admitted students. An ambiguous implicit contract could become the focal point of complaints by dissatisfied parents and students.

The remarks of the former president of Grambling State University to the MAA community in 1997, paraphrased on page 2, suggest that there may be a declining tolerance for high DWF rates. In this age of consumer activism, is it far-fetched to imagine that a group of parents or flunk-outs would organize a class-action lawsuit against a public university for recovery of the tuition they paid for College Algebra—plus damages? How would an academic institution, or a mathematics department chair, explain to a judge the reasons for the DWF rate in College Algebra at their institution?

Science Policy and Precalculus vs. Subcalculus Mathematics

If less than a majority of College Algebra students go on to take calculus of any kind, then it seems more appropriate to refer to this curriculum as subcalculus rather than precalculus.

Should the NSF Support Subcalculus Mathematics Education?

Only a minority of College Algebra students typically go on to take a semester of calculus, but this does not imply that the reformed College Algebra course is terminal mathematics nor that it should lose its significance in the preparation of a scientifically literate citizenry. A *majority* of the College Algebra students will major in subjects that require the study of statistics—business, psychology, the life and health sciences, some social sciences, and even some education programs. Statistics is required in these majors because it is fundamental to understanding phenomena in nature and evaluating the claims of scientific theories.

The American system of higher education should cultivate a scientifically literate electorate as well as scientifically literate policy makers at all levels of government. These people are rarely hard science majors and are far more likely to be College Algebra students than Calculus students. Data collected by the U.S. Department of Education show that only 10% of the college graduates in 1997-98 had hard-science specializations (*Chronicle of Higher Education*, 2001).

Should College Algebra Split into Specialized Courses for Majors?

Large universities may run 20 or 30 sections of College Algebra each year. This presents an opportunity at the least to specialize various sections of the course for different majors and at the extreme to create different *courses* that focus on the needs of different types of students. Monmouth University in New Jersey did just that in 2000-01. Their single College Algebra course had a large number of education majors, and many other students were taking it to fulfill a general education requirement, along with the usual mix of students in business and the social and natural sciences. The math department split the course into four distinct curricula,

- Mathematical Modeling for the Social Sciences took about 250 students, leading to Statistics for most students and to Quantitative Analysis for Business for some.
- Mathematical Modeling for the Biological Sciences split off about 60 students and leads to Statistics.
- Foundations of Elementary Math took nearly 100 education majors and was terminal.
- College Algebra remained as a calculus-preparatory course for majors in the hard sciences and computer science and enrolled about 50 students.

The courses with 50–60 students seemed to be about as small as they could be and still allow enough sections that students would have some flexibility for scheduling. The social sciences course and the biological sciences course had to made interchangeable as prerequisites to their respective majors, because students tended to switch majors between these fields. However, the course for education majors was not interchangeable with those.

Staffing is an issue to consider when subdividing the college algebra course. At Monmouth, the full-time mathematics faculty found it quite interesting to teach the applications of math in the social and biological sciences. Monmouth uses many adjuncts, so the ones with applied math backgrounds were selected for the specialized courses. One point of concern was how well the specialized courses would be taught by adjuncts who were also full-time high school teachers who may not be as comfortable with applications drawn from college-level majors and who may have taught in the traditional manner for many years.

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