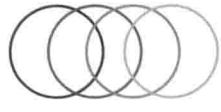
ROBERT T. SMITH
ROLAND B. MINTON

Third Edition

Calculus

EARLY TRANSCENDENTAL FUNCTIONS

Calculus



EARLY TRANSCENDENTAL FUNCTIONS

Third Edition

ROBERT T. SMITH

Millersville University of Pennsylvania

ROLAND B. MINTON

Roanoke College

Higher Education

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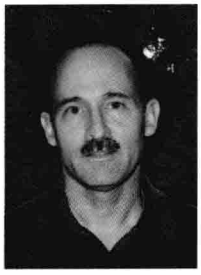
DEDICATION

To Pam, Katie and Michael
To Jan, Kelly and Greg
And our parents—
Thanks for your love and inspiration.

About the Authors



Robert T. Smith is Professor of Mathematics and Chair of the Department of Mathematics at Millersville University of Pennsylvania, where he has taught since 1987. Prior to that, he was on the faculty at Virginia Tech. He earned his Ph.D. in mathematics from the University of Delaware in 1982.

Professor Smith's mathematical interests are in the application of mathematics to problems in engineering and the physical sciences. He has published a number of research articles on the applications of partial differential equations as well as on computational problems in x-ray tomography. He is a member of the American Mathematical Society, the Mathematical Association of America, and the Society for Industrial and Applied Mathematics.

Professor Smith lives in Lancaster, Pennsylvania, with his wife Pam, his daughter Katie and his son Michael. When time permits, he enjoys playing volleyball, tennis, and softball. In his spare time, he coaches youth league soccer. His present extracurricular goal is to learn the game of golf well enough not to come in last in his annual mathematicians/statisticians tournament.

Roland B. Minton is Professor of Mathematics at Roanoke College, where he has taught since 1986. Prior to that, he was on the faculty at Virginia Tech. He earned his Ph.D. from Clemson University in 1982. He is the recipient of the 1998 Roanoke College Exemplary Teaching Award and the 2005 Virginia Outstanding Faculty Award.

Professor Minton has supervised numerous student research projects in such topics as sports science, complexity theory, and fractals. He has published several articles on the use of technology and sports examples in mathematics, in addition to a technical monograph on control theory. He has received grants for teacher training from the State Council for Higher Education in Virginia. He is a member of the Mathematical Association of America, the American Mathematical Society, and other mathematical societies.

Professor Minton lives in Salem, Virginia, with his wife Jan and occasionally with his daughter Kelly and son Greg when they are home from college. He enjoys playing golf and tennis when time permits and watching sports on television even when time doesn't permit. Jan also teaches mathematics at Roanoke College and is very active in mathematics education.

In addition to *Calculus: Early Transcendental Functions,* Professors Smith and Minton are also coauthors of *Calculus: Concepts and Connections* © 2006, and three earlier books for McGraw-Hill Higher Education. The second edition of *Calculus* has been translated into Spanish and is used in several Spanish-speaking countries.

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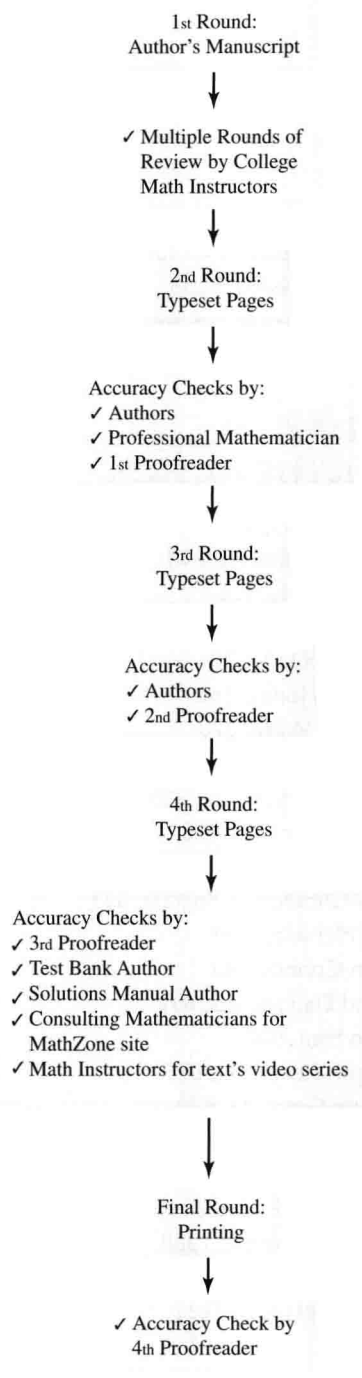

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Step 1: Numerous **college math instructors** review the manuscript and report on any errors that they may find, and the authors make these corrections in their final manuscript.

Second Round

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- A **consulting group of mathematicians,** who write material for the text's MathZone site, notifies the publisher of any errors they encounter in the page proofs.
- A video production company employing **expert math instructors** for the text's videos will alert the publisher of any errors they might find in the page proofs.

Final Round

Step 9: The **project manager,** who has overseen the book from the beginning, performs a **fourth proofread** of the textbook during the printing process, providing a final accuracy review.

⇒ What results is a mathematics textbook that is as accurate and error-free as is humanly possible, and our authors and publishing staff are confident that our many layers of quality assurance have produced textbooks that are the leaders of the industry for their integrity and correctness.

Preface

The wide-ranging debate brought about by the calculus reform movement has had a significant impact on calculus textbooks. In response to many of the questions and concerns surrounding this debate, we have written a modern calculus textbook, intended for students majoring in mathematics, physics, chemistry, engineering, and related fields.

Our intention is that students should be able to read our book, rather than merely use it as an encyclopedia filled with the facts of calculus. We have written in a conversational style that reviewers have compared to listening to a good lecture. Our sense of what works well with students has been honed by teaching mathematics for more than a combined 50 years at a variety of colleges and universities, both public and private, ranging from a small liberal arts college to large engineering schools.

In an effort to ensure that this textbook successfully addresses our concerns about the effective teaching of calculus we have continually asked instructors around the world for their opinions on the calculus curriculum, the strengths and weaknesses of current textbooks, and the strengths and weaknesses of our own text. In preparing this third edition, as with the previous editions, we enjoyed the benefit of countless insightful comments from a talented panel of reviewers that was selected to help us with this project.

OUR PHILOSOPHY

We agree with many of the ideas that have come out of the calculus reform movement. In particular, we believe in the **Rule of Four:** that concepts should be presented **graphically, numerically, algebraically** and **verbally,** whenever these are appropriate. In fact, we would add **physically** to this list, since the modeling of physical problems is an important skill that students need to develop. We also believe that, while the calculus curriculum has been in need of reform, we should not throw out those things that already work well. Our book thus represents an updated approach to the traditional topics of calculus. We follow a mainstream order of presentation, while integrating technology and thought-provoking exercises throughout.

One of the thrusts of the calculus reform movement has been to place greater emphasis on problem solving and to present students with more realistic applications as well as open-ended problems. We have incorporated meaningful writing exercises and extended, open-ended problems into **every problem set.** You will also find a **much wider range of applications** than in most traditional texts. We make frequent use of applications from students' experience both to **motivate the development of new topics** and to illustrate concepts we have already presented. In particular, we have included numerous examples from a wide range of fields to give students a familiar context in which to think of various concepts and their applications.

We believe that a conceptual development of the calculus must motivate the text. Although we have **integrated technology throughout,** we have not allowed the technology to drive the book. Our goal is to use the available technology to help students reach a conceptual understanding of the calculus as it is used today.

MOTIVATION AND UNDERSTANDING

Perhaps the most important task when preparing a calculus text is the actual *writing* of it. We have endeavored to write this text in a manner that combines an appropriate level of informality with an honest discussion regarding the difficulties that students commonly face in their study of calculus. In addition to the concepts and applications of calculus, we have also included many frank discussions about what is practical and impractical, and what is difficult and not so difficult to students in the course.

Our primary objectives are to find better ways to motivate students and facilitate their understanding. To accomplish this, we go beyond the standard textbook presentation and tell students **why** they are learning something, **how** they will use it, and **why** it is important. As a result students master problem-solving skills while also **learning how to think mathematically,** an important goal for most instructors teaching the calculus course.

This edition of our text incorporates an early introduction to all transcendental functions. Our students have seen these functions before they ever set foot in a calculus classroom, so we would like to take advantage of their familiarity. We introduce the calculus of these functions in Chapter 2, along with the other rules of differentiation. We have found that this early introduction allows for more varied examples and exercises in the applications of differentiation (including graphing), integration, and applications of integration.

In our view, techniques of integration remain of great importance. Our emphasis is on helping students develop the ability to carefully distinguish among similar-looking integrals and identify the appropriate technique of integration to apply to each integral. The attention to detail and mathematical sophistication required by this process are invaluable skills. We do not attempt to be encyclopedic about techniques of integration, especially given the widespread use of computer algebra systems. Accordingly, in section 6.5, we include a discussion of integration tables and the use of computer algebra systems for performing symbolic integration.

In addition to a focus on the central concepts of calculus, we have included several sections that are not typically found in other calculus texts, as well as expanded coverage of specific topics. This provides instructors with the flexibility to tailor their courses to the interests and abilities of each class.

- For instance, in section 1.7, we explore **loss-of significance errors.** Here, we discuss how computers and calculators perform arithmetic operations and how these can cause errors, in the context of numerical approximation of limits.
- In section 3.9, we present a diverse group of applications of differentiation, including **chemical reaction rates and heart rates.**
- Separable differential equations and logistic growth are discussed in section 7.2, followed by direction fields and Euler's method for first-order ordinary differential equations in section 7.3.
- In Chapter 8, we follow our discussion of power series and Taylor's Theorem with a section on **Fourier series.**
- In sections 9.1–9.3 we provide **expanded coverage of parametric equations.**
- In section 10.4 we include a discussion of **Magnus force.**

CALCULUS AND TECHNOLOGY

It is our conviction that graphing calculators and computer algebra systems must not be used indiscriminately. The focus must always remain on the calculus. We have ensured that each of our exercise sets offers an extensive array of problems that should be worked by hand. We also believe, however, that calculus study supplemented with an intelligent use of technology gives students an extremely powerful arsenal of problem-solving skills. Many passages in the text provide guidance on how to judiciously use—and not abuse—graphing calculators and computers. We also provide ample opportunity for students to practice using these tools. Exercises that are most easily solved with the aid of a graphing calculator or a computer algebra system are easily identified with a  icon.

IMPROVEMENTS IN THE THIRD EDITION

Building upon the success of the Second Edition of *Calculus,* we have made the following revisions to produce an even better Third Edition:

Organization

- **All transcendental functions are introduced early,** and their calculus is covered with the calculus of algebraic functions, to accommodate instructors who prefer this approach.
- **Differential equations** receive substantially more coverage in Chapter 7 and in the **all-new** Chapter 15.

Presentation

- A **thorough rewrite** of the book resulted in a **more concise and direct presentation** of all concepts and techniques.
- The **multivariable chapters** were thoroughly revised in response to user feedback to provide a **more cogent and refined** presentation of this material.
- The entire text was redesigned for a **more open, clean appearance** to aid students in locating and focusing on essential information.

Exercises

- **More challenging exercises** appear throughout the book, and ***Exploratory Exercises*** **conclude every section** to encourage students to synthesize what they've learned.
- **Technology icons** now appear next to all exercises requiring the use of a computer algebra system.

Aesthetics and Relevance of Mathematics

- *NEW* ***Beyond Formulas*** boxes appear in every chapter to encourage students to **think mathematically** and go beyond routine answer calculation.
- *NEW* ***Today in Mathematics*** boxes appear in every chapter showing students that mathematics is a dynamic discipline with many discoveries continually being made by **people inspired by the beauty of the subject.**

- *NEW* The ***Index of Applications*** shows students of diverse majors the **immediate relevance** of what they are studying.

SUPPLEMENTS

INSTRUCTOR'S SOLUTIONS MANUAL (ISBN 978-0-07-321325-5)

An invaluable, timesaving resource, the Instructor's Solutions Manual contains comprehensive, worked-out solutions to the odd- and even-numbered exercises in the text.

STUDENT SOLUTIONS MANUAL (ISBN 978-0-07-286957-6)

The Student Solutions Manual is a helpful reference that contains comprehensive, worked-out solutions to the odd-numbered exercises in the text.

INSTRUCTOR'S TESTING AND RESOURCE CD-ROM (ISBN 978-0-07-286962-0)

Brownstone Diploma® testing software, available on CD-ROM, offers instructors a quick and easy way to create customized exams and view student results. Instructors may use the software to sort questions by section, difficulty level, and type; add questions and edit existing questions; create multiple versions of questions using algorithmically-randomized variables; prepare multiple-choice quizzes; and construct a grade book.

MathZone www.mathzone.com

McGraw-Hill's MathZone is a cutting-edge, customizable web-based system that offers a complete solution to instructors' online homework, quizzing and testing needs. MathZone guides students through step-by-step solutions to practice problems and facilitates student assessment through the use of algorithmically-generated test questions. Student activity within the MathZone site is **automatically graded** and accessible to instructors in an integrated, exportable grade book.

MathZone also provides a wide variety of **interactive student tutorials,** including **new applets for every section** in the book to give students interactive practice on important concepts and procedures; algorithmic practice problems; **e-Professor,** a collection of step-by-step animated instructions for solving exercises from the text; **Calculus Concepts Videos;** and **NetTutor,** a live, personalized tutoring service offered via the Internet.

CALCULUS CONCEPTS VIDEOS (978-0-07-312476-6)

Students will see **essential concepts** explained and brought to life through **dynamic animations** in this new video series available on DVD and on the Smith/Minton MathZone site. The **twenty-five key concepts,** chosen after consultation with calculus instructors across the country, are the most commonly taught topics that students need help with and that also lend themselves most readily to on-camera demonstration.

ALEKS PREP FOR CALCULUS

ALEKS (**A**ssessment and **LE**arning in **K**nowledge **S**paces) is an artificial intelligence-based system for mathematics learning, available online 24/7. Using unique adaptive questioning, ALEKS accurately assesses what topics each student knows and then determines exactly what each student is ready to learn next. ALEKS interacts with the students much as a skilled

human tutor would, moving between explanation and practice as needed, correcting and analyzing errors, defining terms and changing topics on request, and helping them master the course content more quickly and easily. **New ALEKS 3.0** now links to text-specific videos, multimedia tutorials, and textbook pages in PDF format. ALEKS also offers a robust classroom management system that allows instructors to monitor and direct student progress toward mastery of curricular goals. See www.highed.aleks.com.

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A project of this magnitude requires the collaboration of an incredible number of talented and dedicated individuals. Our editorial staff worked tirelessly to provide us with countless surveys, focus group reports, and reviews, giving us the best possible read on the current state of calculus instruction. First and foremost, we want to express our appreciation to our sponsoring editor Liz Covello and our developmental editor Randy Welch for their encouragement and support to keep us on track throughout this project. They challenged us to make this a better book. We also wish to thank our publisher Liz Haefele, and director of development David Dietz for their ongoing strong support.

We are indebted to the McGraw-Hill production team, especially project manager Peggy Selle and design coordinator David Hash, for (among other things) producing a beautifully designed text. Cindy Trimble and Santo D'Agostino provided us with numerous suggestions for clarifying and improving the exercise sets and ensuring the text's accuracy. Our marketing manager Dawn Bercier has been instrumental in helping to convey the story of this book to a wider audience, and media producer Jeff Huettman created an innovative suite of media supplements.

Our work on this project benefited tremendously from the insightful comments we received from many reviewers, survey respondents and symposium attendees. We wish to thank the following individuals whose contributions helped to shape this book:

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Guided Tour

TOOLS FOR LEARNING

Real-World Emphasis

Each chapter opens with a real-world application that illustrates the usefulness of the concepts being developed and motivates student interest.

Parametric Equations and Polar Coordinates

CHAPTER 9

You are all familiar with sonic booms, those loud crashes of noise caused by aircraft flying faster than the speed of sound. You may have even heard a sonic boom, but you have probably never *seen* a sonic boom. The remarkable photograph here shows water vapor outlining the surface of a shock wave created by an F-18 jet flying supersonically. (Note that there is also a small cone of water vapor trailing the back of the cockpit of the jet.)

You may be surprised at the apparently conical shape assumed by the shock waves. A mathematical analysis of the shock waves verifies that the shape is indeed conical. (You will have an opportunity to explore this in the exercises in section 9.1.) To visualize how sound waves propagate, imagine an exploding firecracker. If you think of this in two dimensions, you'll recognize that the sound waves propagate in a series of ever-expanding concentric circles that reach everyone standing a given distance away from the firecracker at the same time.

In this chapter, we extend the concepts of calculus to curves described by parametric equations and polar coordinates. For instance, in order to study the motion of an object such as an airplane in two dimensions, we would need to describe the object's position (x, y) as a function of the parameter t (time). That is, we write the position in the form $(x, y) = (x(t), y(t))$, where $x(t)$ and $y(t)$ are functions to which our existing techniques of calculus can be applied. The equations $x = x(t)$ and $y = y(t)$ are called parametric equations. Additionally, we'll explore how to use polar coordinates to represent curves, not as a set of points (x, y), but rather, by specifying the points by the distance from the origin to the point and an angle corresponding to the direction from the origin to the point. Polar coordinates are especially convenient for describing circles, such as those that occur in propagating sound waves.

These alternative descriptions of curves bring us a great deal of needed flexibility in attacking many problems. Often, even very complicated looking curves have a simple description in terms of parametric equations or polar coordinates. We explore a variety of interesting curves in this chapter and see how to extend the methods of calculus to such curves.

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