

Volume 1

SINGLE VARIABLE

Calculus

James Stewart 5e

single variable
CALCULUS

fifth edition

Volume 1: Chapters 1–6

JAMES STEWART
McMaster University

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PREFACE

A great discovery solves a great problem but there is a grain of discovery in the solution of any problem. Your problem may be modest; but if it challenges your curiosity and brings into play your inventive faculties, and if you solve it by your own means, you may experience the tension and enjoy the triumph of discovery.

GEORGE POLYA

The art of teaching, Mark Van Doren said, is the art of assisting discovery. I have tried to write a book that assists students in discovering calculus—both for its practical power and its surprising beauty. In this edition, as in the first four editions, I aim to convey to the student a sense of the utility of calculus and develop technical competence, but I also strive to give some appreciation for the intrinsic beauty of the subject. Newton undoubtedly experienced a sense of triumph when he made his great discoveries. I want students to share some of that excitement.

The emphasis is on understanding concepts. I think that nearly everybody agrees that this should be the primary goal of calculus instruction. In fact, the impetus for the current calculus reform movement came from the Tulane Conference in 1986, which formulated as their first recommendation:

Focus on conceptual understanding.

I have tried to implement this goal through the *Rule of Three*: “Topics should be presented geometrically, numerically, and algebraically.” Visualization, numerical and graphical experimentation, and other approaches have changed how we teach conceptual reasoning in fundamental ways. More recently, the Rule of Three has been expanded to become the *Rule of Four* by emphasizing the verbal, or descriptive, point of view as well.

In writing the fifth edition my premise has been that it is possible to achieve conceptual understanding and still retain the best traditions of traditional calculus. The book contains elements of reform, but within the context of a traditional curriculum. (Instructors who prefer a more streamlined curriculum should look at my book *Calculus: Concepts and Contexts, Second Edition*.)

What's New in the Fifth Edition

By way of preparing to write the fifth edition of this text, I spent a year teaching calculus from the fourth edition at the University of Toronto. I listened carefully to my students' questions and my colleagues' suggestions. And as I prepared each lecture I sometimes realized that an additional example was needed, or a sentence could be clarified, or a section could use a few more exercises of a certain type. In addition, I paid attention to the suggestions sent to me by many users and to the comments of the reviewers.

The structure of *Single Variable Calculus, Fifth Edition*, remains largely unchanged, but there are hundreds of improvements, small and large:

- New phrases and margin notes have been added to clarify the exposition.
- A number of pieces of art have been redrawn.
- The data in examples and exercises have been updated to be more timely.
- Examples have been added. For instance, I added the new Example 1 in Section 5.3 (pages 340–341) because students have a tough time grasping the idea of a function defined by an integral with a variable limit of integration. I think it helps to look at Example 1 before considering the Fundamental Theorem of Calculus.
- Extra steps have been provided in some of the existing examples.
- More than 25% of the exercises in each chapter are new. Two of my favorites are Exercise 34 in Section 3.1 (page 133) and Exercise 52 in Section 5.4 (page 357).
- I've also added new problems to the Problems Plus sections. See, for instance, Problem 20 on page 221.
- One new project has been added (see page 198). It asks students to design a roller coaster so the track is smooth at transition points.
- A CD called *Tools for Enriching Calculus (TEC)* is available for use with the fifth edition. See the description on page x.
- Conscious of the need to control the size of the book, I've put additional topics (with exercises) on the revamped web site www.stewartcalculus.com (see the description on page xi) rather than in the text itself. These include the new topics Fourier Series and Formulas for the Remainder Term in Taylor Series, as well as topics that appeared in previous editions: Review of Basic Algebra, Rotation of Axes, and Lies My Calculator and Computer Told Me.



Features

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|-----------------------------|--|
| Conceptual Exercises | The most important way to foster conceptual understanding is through the problems that we assign. To that end I have devised various types of new problems. Some exercise sets begin with requests to explain the meanings of the basic concepts of the section. (See, for instance, the first few exercises in Sections 2.2, 2.5, and 2.6.) Similarly, all the review sections begin with a <i>Concept Check</i> and a <i>True-False Quiz</i> . Other exercises test conceptual understanding through graphs or tables (see Exercises 3.1.1–3, 3.2.33–36, and 3.8.1–4).
Another type of exercise uses verbal description to test conceptual understanding (see Exercises 2.5.8, 3.2.46, and 4.3.47–48). I particularly value problems that combine and compare graphical, numerical, and algebraic approaches (see Exercises 4.4.33–34, and 3.4.23). |
| Graded Exercise Sets | Each exercise set is carefully graded, progressing from basic conceptual exercises and skill-development problems to more challenging problems involving applications and proofs. |
| Real-World Data | My assistants and I spent a great deal of time looking in libraries, contacting companies and government agencies, and searching the Internet for interesting real-world data to introduce, motivate, and illustrate the concepts of calculus. As a result, many of the examples and exercises deal with functions defined by such numerical data or graphs. See, for instance, Figures 1, 11, and 12 in Section 1.1 (seismograms from the Northridge earth- |

quake), Exercise 3.2.34 (percentage of the population under age 18), Exercise 5.1.14 (velocity of the space shuttle *Endeavour*), and Figure 4 in Section 5.4 (San Francisco power consumption).

Projects One way of involving students and making them active learners is to have them work (perhaps in groups) on extended projects that give a feeling of substantial accomplishment when completed. I have included four kinds of projects: *Applied Projects* involve applications that are designed to appeal to the imagination of students. *Laboratory Projects* involve technology. *Writing Projects* ask students to compare present-day methods with those of the founders of calculus. Suggested references are supplied. *Discovery Projects* anticipate results to be discussed later or encourage discovery through pattern recognition. Additional projects can be found in the *Instructor's Guide* (see, for instance, Group Exercise 5.1: Position from Samples) and also in the *CalcLabs* supplements.

Problem Solving Students usually have difficulties with problems for which there is no single well-defined procedure for obtaining the answer. I think nobody has improved very much on George Polya's four-stage problem-solving strategy and, accordingly, I have included a version of his problem-solving principles following Chapter 1. They are applied, both explicitly and implicitly, throughout the book. After the other chapters I have placed sections called *Problems Plus*, which feature examples of how to tackle challenging calculus problems. In selecting the varied problems for these sections I kept in mind the following advice from David Hilbert: "A mathematical problem should be difficult in order to entice us, yet not inaccessible lest it mock our efforts." When I put these challenging problems on assignments and tests I grade them in a different way. Here I reward a student significantly for ideas toward a solution and for recognizing which problem-solving principles are relevant.

Technology The availability of technology makes it not less important but more important to clearly understand the concepts that underlie the images on the screen. But, when properly used, graphing calculators and computers are powerful tools for discovering and understanding those concepts. This textbook can be used either with or without technology and I use two special symbols to indicate clearly when a particular type of machine is required. The icon  indicates an exercise that definitely requires the use of such technology, but that is not to say that it can't be used on the other exercises as well. The symbol  is reserved for problems in which the full resources of a computer algebra system (like Derive, Maple, Mathematica, or the TI-89/92) are required. But technology doesn't make pencil and paper obsolete. Hand calculation and sketches are often preferable to technology for illustrating and reinforcing some concepts. Both instructors and students need to develop the ability to decide where the hand or the machine is appropriate.



Tools for Enriching™ Calculus

The CD-ROM called *TEC* is a companion to the text and is intended to enrich and complement its contents. Developed by Harvey Keynes at the University of Minnesota and Dan Clegg at Palomar College, *TEC* uses a discovery and exploratory approach. In sections of the book where technology is particularly appropriate, marginal icons direct students to *TEC* modules that provide a laboratory environment in which they can explore the topic in different ways and at different levels. Instructors can choose to become involved at several different levels, ranging from simply encouraging students to use the modules for independent exploration, to assigning specific exercises from those included with each module, or to creating additional exercises, labs, and projects that make use of the modules.

TEC also includes *homework hints* for representative exercises (usually odd-numbered) in every section of the text, indicated by printing the exercise number in red. These hints are usually presented in the form of questions and try to imitate an effective teaching assis-

tant by functioning as a silent tutor. They are constructed so as not to reveal any more of the actual solution than is minimally necessary to make further progress.

Web Site: www.stewartcalculus.com

This site has been renovated and now includes the following.

- Algebra Review, with tutorial
- Additional Topics (complete with exercise sets): Fourier Series, Formulas for the Remainder Term in Taylor Series, Rotation of Axes, Lies My Calculator and Computer Told Me
- Drill exercises that appeared in previous editions, together with their solutions
- Problems Plus from prior editions
- Links, for particular topics, to outside web resources
- History of Mathematics, with links to the better historical web sites
- Downloadable versions of *CalcLabs* for Derive and TI graphing calculators

Content

This volume consists of the first six chapters of *Single Variable Calculus, Fifth Edition*.

- | | |
|-------------------------------------|---|
| A Preview of Calculus | The book begins with an overview of the subject and includes a list of questions to motivate the study of calculus. |
| 1 ▫ Functions and Models | From the beginning, multiple representations of functions are stressed: verbal, numerical, visual, and algebraic. A discussion of mathematical models leads to a review of the standard functions from these four points of view. |
| 2 ▫ Limits and Rates of Change | The material on limits is motivated by a prior discussion of the tangent and velocity problems. Limits are treated from descriptive, graphical, numerical, and algebraic points of view. Section 2.4, on the precise ϵ - δ definition of a limit, is an optional section. |
| 3 ▫ Derivatives | The material on derivatives is covered in two sections in order to give students more time to get used to the idea of a derivative as a function. The examples and exercises explore the meanings of derivatives in various contexts. |
| 4 ▫ Applications of Differentiation | The basic facts concerning extreme values and shapes of curves are deduced from the Mean Value Theorem. Graphing with technology emphasizes the interaction between calculus and calculators and the analysis of families of curves. Some substantial optimization problems are provided, including an explanation of why you need to raise your head 42° to see the top of a rainbow. |
| 5 ▫ Integrals | The area problem and the distance problem serve to motivate the definite integral, with sigma notation introduced as needed. (Full coverage of sigma notation is provided in Appendix E.) Emphasis is placed on explaining the meanings of integrals in various contexts and on estimating their values from graphs and tables. |
| 6 ▫ Applications of Integration | Here I present the applications of integration—area, volume, work, average value—that can reasonably be done without specialized techniques of integration. General methods are emphasized. The goal is for students to be able to divide a quantity into small pieces, estimate with Riemann sums, and recognize the limit as an integral. |

Ancillaries

Single Variable Calculus, Fifth Edition, is supported by a complete set of ancillaries developed under my direction. Each piece has been designed to enhance student understanding and to facilitate creative instruction. The tables on pages xvi–xvii describe each of these ancillaries.

Acknowledgments

The preparation of this and previous editions has involved much time spent reading the reasoned (but sometimes contradictory) advice from a large number of astute reviewers. I greatly appreciate the time they spent to understand my motivation for the approach taken. I have learned something from each of them.

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JAMES STEWART

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Each of these comprehensive lab manuals will help students learn to effectively use the technology tools available to them. Each lab contains clearly explained exercises and a variety of labs and projects to accompany the text.

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by Dennis Ebersole, Doris Schattschneider,

Alicia Sevilla, and Kay Somers

ISBN 0-534-26592-8

Written to improve algebra and problem-solving skills of students taking a calculus course, every chapter in this companion is keyed to a calculus topic, providing conceptual background and specific algebra techniques needed to understand and solve calculus problems related to that topic. It is designed for calculus courses that integrate the review of pre-calculus concepts or for individual use.

Linear Algebra for Calculus

by Konrad J. Heuvers, William P. Francis,

John H. Kuisti, Deborah F. Lockhart, Daniel S. Moak,

and Gene M. Ortner

ISBN 0-534-25248-6

This comprehensive book, designed to supplement the calculus course, provides an introduction to and review of the basic ideas of linear algebra.



TO THE STUDENT


Reading a calculus textbook is different from reading a newspaper or a novel, or even a physics book. Don't be discouraged if you have to read a passage more than once in order to understand it. You should have pencil and paper and calculator at hand to sketch a diagram or make a calculation.


Some students start by trying their homework problems and read the text only if they get stuck on an exercise. I suggest that a far better plan is to read and understand a section of the text before attempting the exercises. In particular, you should look at the definitions to see the exact meanings of the terms. And before you read each example, I suggest that you cover up the solution and try solving the problem yourself. You'll get a lot more from looking at the solution if you do so.


Part of the aim of this course is to train you to think logically. Learn to write the solutions of the exercises in a connected, step-by-step fashion with explanatory sentences—not just a string of disconnected equations or formulas.

The answers to the odd-numbered exercises appear at the back of the book, in Appendix H. Some exercises ask for a verbal explanation or interpretation or description. In such cases there is no single correct way of expressing the answer, so don't worry that you haven't found the definitive answer. In addition, there are often several different forms in which to express a numerical or algebraic answer, so if your answer differs from mine, don't immediately assume you're wrong. For example, if the answer given in the back of the book is $\sqrt{2} - 1$ and you obtain $1/(1 + \sqrt{2})$, then you're right and rationalizing the denominator will show that the answers are equivalent.

The icon  indicates an exercise that definitely requires the use of either a graphing calculator or a computer with graphing software. (Section 1.4 discusses the use of these graphing devices and some of the pitfalls that you may encounter.) But that doesn't mean that graphing devices can't be used to check your work on the other exercises as well. The symbol  is reserved for problems in which the full resources of a computer algebra system (like Derive, Maple, Mathematica, or the TI-89/92) are required.

You will also encounter the symbol , which warns you against committing an error. I have placed this symbol in the margin in situations where I have observed that a large proportion of my students tend to make the same mistake.

The icon  indicates a reference to the CD-ROM *Journey Through Calculus*. The symbols in the margin refer you to the location in *Journey* where a concept is introduced through an interactive exploration or animation.

The CD-ROM *Tools for Enriching Calculus* (see inside front cover for availability) is referred to by means of the symbol . It directs you to modules in which you can explore aspects of calculus for which the computer is particularly useful. *TEC* also provides *Homework Hints* for representative exercises that are indicated by printing the exercise number in red: **23**. These homework hints ask you questions that allow you to make progress toward a solution without actually giving you the answer. You need to pursue each hint in an active manner with pencil and paper to work out the details. If a particular hint doesn't enable you to solve the problem, you can click to reveal the next hint.

The CD-ROM *Interactive Video Skillbuilder* (see inside front cover for availability) contains videos of instructors explaining two or three of the examples in every section of the text. Also on the CD is a video in which I offer advice on how to succeed in your calculus course.

I recommend that you keep this book for reference purposes after you finish the course. Because you will likely forget some of the specific details of calculus, the book will serve as a useful reminder when you need to use calculus in subsequent courses. And, because this book contains more material than can be covered in any one course, it can also serve as a valuable resource for a working scientist or engineer.

Calculus is an exciting subject, justly considered to be one of the greatest achievements of the human intellect. I hope you will discover that it is not only useful but also intrinsically beautiful.

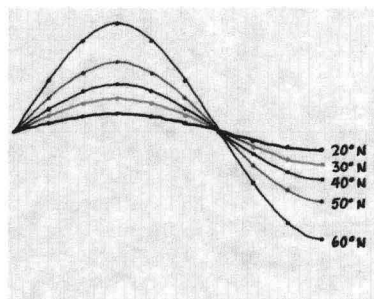
JAMES STEWART

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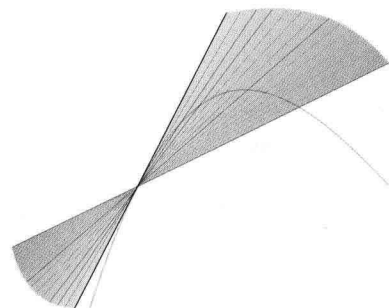
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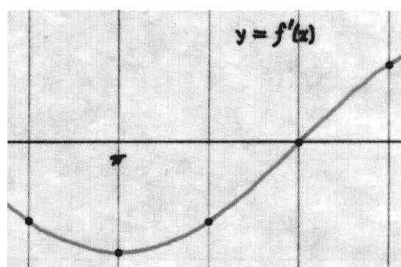
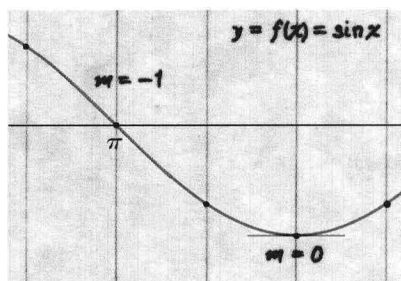
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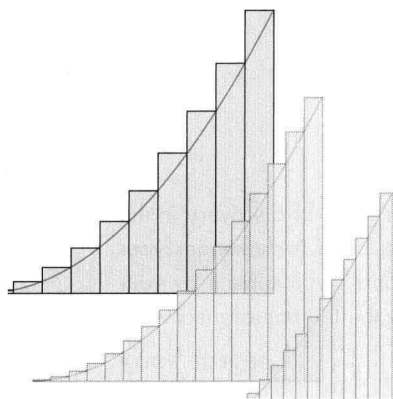
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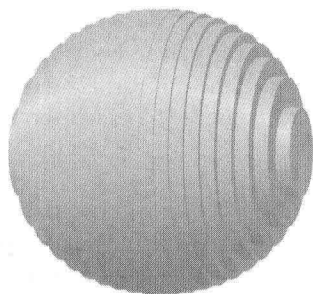
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