

# College Physics

**By:** OpenStax College

**Online:** <<http://cnx.org/content/col11406/1.7>>

This selection and arrangement of content as a collection is copyrighted by Rice University.

Creative Commons Attribution License 3.0 <http://creativecommons.org/licenses/by/3.0/>

Collection structure revised: 2012/06/12

For copyright and attribution information for the modules contained in this collection, see the "**Attributions**" section at the end of the collection.



# Table of Contents

<b>Preface</b> . . . . .	<b>7</b>
<b>1 Introduction: The Nature of Science and Physics</b> . . . . .	<b>11</b>
Physics: An Introduction . . . . .	11
Physical Quantities and Units . . . . .	18
Accuracy, Precision, and Significant Figures . . . . .	24
Approximation . . . . .	28
<b>2 Kinematics</b> . . . . .	<b>35</b>
Displacement . . . . .	36
Vectors, Scalars, and Coordinate Systems . . . . .	38
Time, Velocity, and Speed . . . . .	39
Acceleration . . . . .	43
Motion Equations for Constant Acceleration in One Dimension . . . . .	51
Problem-Solving Basics for One-Dimensional Kinematics . . . . .	61
Falling Objects . . . . .	62
Graphical Analysis of One-Dimensional Motion . . . . .	69
<b>3 Two-Dimensional Kinematics</b> . . . . .	<b>87</b>
Kinematics in Two Dimensions: An Introduction . . . . .	88
Vector Addition and Subtraction: Graphical Methods . . . . .	90
Vector Addition and Subtraction: Analytical Methods . . . . .	97
Projectile Motion . . . . .	103
Addition of Velocities . . . . .	110
<b>4 Dynamics: Force and Newton's Laws of Motion</b> . . . . .	<b>127</b>
Development of Force Concept . . . . .	128
Newton's First Law of Motion: Inertia . . . . .	129
Newton's Second Law of Motion: Concept of a System . . . . .	130
Newton's Third Law of Motion: Symmetry in Forces . . . . .	136
Normal, Tension, and Other Examples of Forces . . . . .	138
Problem-Solving Strategies . . . . .	146
Further Applications of Newton's Laws of Motion . . . . .	148
Extended Topic: The Four Basic Forces—An Introduction . . . . .	154
<b>5 Further Applications of Newton's Laws: Friction, Drag, and Elasticity</b> . . . . .	<b>167</b>
Friction . . . . .	168
Drag Forces . . . . .	172
Elasticity: Stress and Strain . . . . .	176
<b>6 Uniform Circular Motion and Gravitation</b> . . . . .	<b>191</b>
Rotation Angle and Angular Velocity . . . . .	191
Centripetal Acceleration . . . . .	195
Centripetal Force . . . . .	198
Fictitious Forces and Non-inertial Frames: The Coriolis Force . . . . .	202
Newton's Universal Law of Gravitation . . . . .	205
Satellites and Kepler's Laws: An Argument for Simplicity . . . . .	211
<b>7 Work, Energy, and Energy Resources</b> . . . . .	<b>225</b>
Work: The Scientific Definition . . . . .	225
Kinetic Energy and the Work-Energy Theorem . . . . .	228
Gravitational Potential Energy . . . . .	232
Conservative Forces and Potential Energy . . . . .	237
Nonconservative Forces . . . . .	240
Conservation of Energy . . . . .	244
Power . . . . .	247
Work, Energy, and Power in Humans . . . . .	251
World Energy Use . . . . .	253
<b>8 Linear Momentum and Collisions</b> . . . . .	<b>265</b>
Linear Momentum and Force . . . . .	265
Impulse . . . . .	267
Conservation of Momentum . . . . .	269
Elastic Collisions in One Dimension . . . . .	272
Inelastic Collisions in One Dimension . . . . .	274
Collisions of Point Masses in Two Dimensions . . . . .	278
Introduction to Rocket Propulsion . . . . .	281
<b>9 Statics and Torque</b> . . . . .	<b>293</b>
The First Condition for Equilibrium . . . . .	294
The Second Condition for Equilibrium . . . . .	295
Stability . . . . .	299
Applications of Statics, Including Problem-Solving Strategies . . . . .	302
Simple Machines . . . . .	305
Forces and Torques in Muscles and Joints . . . . .	308
<b>10 Rotational Motion and Angular Momentum</b> . . . . .	<b>321</b>
Angular Acceleration . . . . .	322
Kinematics of Rotational Motion . . . . .	326
Dynamics of Rotational Motion: Rotational Inertia . . . . .	330
Rotational Kinetic Energy: Work and Energy Revisited . . . . .	334

Angular Momentum and Its Conservation . . . . .	340
Collisions of Extended Bodies in Two Dimensions . . . . .	345
Gyroscopic Effects: Vector Aspects of Angular Momentum . . . . .	348
<b>11 Fluid Statics . . . . .</b>	<b>361</b>
What Is a Fluid? . . . . .	361
Density . . . . .	362
Pressure . . . . .	364
Variation of Pressure with Depth in a Fluid . . . . .	366
Pascal's Principle . . . . .	369
Gauge Pressure, Absolute Pressure, and Pressure Measurement . . . . .	372
Archimedes' Principle . . . . .	375
Cohesion and Adhesion in Liquids: Surface Tension and Capillary Action . . . . .	381
Pressures in the Body . . . . .	388
<b>12 Fluid Dynamics and Its Biological and Medical Applications . . . . .</b>	<b>401</b>
Flow Rate and Its Relation to Velocity . . . . .	401
Bernoulli's Equation . . . . .	404
The Most General Applications of Bernoulli's Equation . . . . .	408
Viscosity and Laminar Flow; Poiseuille's Law . . . . .	411
The Onset of Turbulence . . . . .	417
Motion of an Object in a Viscous Fluid . . . . .	418
Molecular Transport Phenomena: Diffusion, Osmosis, and Related Processes . . . . .	420
<b>13 Temperature, Kinetic Theory, and the Gas Laws . . . . .</b>	<b>433</b>
Temperature . . . . .	433
Thermal Expansion of Solids and Liquids . . . . .	440
The Ideal Gas Law . . . . .	446
Kinetic Theory: Atomic and Molecular Explanation of Pressure and Temperature . . . . .	451
Phase Changes . . . . .	457
Humidity, Evaporation, and Boiling . . . . .	462
<b>14 Heat and Heat Transfer Methods . . . . .</b>	<b>473</b>
Heat . . . . .	473
Temperature Change and Heat Capacity . . . . .	475
Phase Change and Latent Heat . . . . .	479
Heat Transfer Methods . . . . .	484
Conduction . . . . .	485
Convection . . . . .	489
Radiation . . . . .	493
<b>15 Thermodynamics . . . . .</b>	<b>507</b>
The First Law of Thermodynamics . . . . .	508
The First Law of Thermodynamics and Some Simple Processes . . . . .	512
Introduction to the Second Law of Thermodynamics: Heat Engines and Their Efficiency . . . . .	519
Carnot's Perfect Heat Engine: The Second Law of Thermodynamics Restated . . . . .	524
Applications of Thermodynamics: Heat Pumps and Refrigerators . . . . .	528
Entropy and the Second Law of Thermodynamics: Disorder and the Unavailability of Energy . . . . .	532
Statistical Interpretation of Entropy and the Second Law of Thermodynamics: The Underlying Explanation . . . . .	538
<b>16 Oscillatory Motion and Waves . . . . .</b>	<b>551</b>
Hooke's Law: Stress and Strain Revisited . . . . .	552
Period and Frequency in Oscillations . . . . .	556
Simple Harmonic Motion: A Special Periodic Motion . . . . .	557
The Simple Pendulum . . . . .	561
Energy and the Simple Harmonic Oscillator . . . . .	563
Uniform Circular Motion and Simple Harmonic Motion . . . . .	565
Damped Harmonic Motion . . . . .	568
Forced Oscillations and Resonance . . . . .	571
Waves . . . . .	573
Superposition and Interference . . . . .	575
Energy in Waves: Intensity . . . . .	579
<b>17 Physics of Hearing . . . . .</b>	<b>591</b>
Sound . . . . .	592
Speed of Sound, Frequency, and Wavelength . . . . .	593
Sound Intensity and Sound Level . . . . .	596
Doppler Effect and Sonic Booms . . . . .	600
Sound Interference and Resonance: Standing Waves in Air Columns . . . . .	604
Hearing . . . . .	610
Ultrasound . . . . .	615
<b>18 Electric Charge and Electric Field . . . . .</b>	<b>629</b>
Static Electricity and Charge: Conservation of Charge . . . . .	630
Conductors and Insulators . . . . .	634
Coulomb's Law . . . . .	638
Electric Field: Concept of a Field Revisited . . . . .	639
Electric Field Lines: Multiple Charges . . . . .	641
Electric Forces in Biology . . . . .	644
Conductors and Electric Fields in Static Equilibrium . . . . .	645
Applications of Electrostatics . . . . .	649

<b>19 Electric Potential and Electric Field</b>	<b>665</b>
Electric Potential Energy: Potential Difference	665
Electric Potential in a Uniform Electric Field	670
Electrical Potential Due to a Point Charge	673
Equipotential Lines	675
Capacitors and Dielectrics	677
Capacitors in Series and Parallel	683
Energy Stored in Capacitors	686
<b>20 Electric Current, Resistance, and Ohm's Law</b>	<b>697</b>
Current	698
Ohm's Law: Resistance and Simple Circuits	703
Resistance and Resistivity	704
Electric Power and Energy	709
Alternating Current versus Direct Current	712
Electric Hazards and the Human Body	716
Nerve Conduction—Electrocardiograms	719
<b>21 Circuits, Bioelectricity, and DC Instruments</b>	<b>735</b>
Resistors in Series and Parallel	735
Electromotive Force: Terminal Voltage	743
Kirchhoff's Rules	750
DC Voltmeters and Ammeters	754
Null Measurements	758
DC Circuits Containing Resistors and Capacitors	761
<b>22 Magnetism</b>	<b>775</b>
Magnets	776
Ferromagnets and Electromagnets	777
Magnetic Fields and Magnetic Field Lines	781
Magnetic Field Strength: Force on a Moving Charge in a Magnetic Field	782
Force on a Moving Charge in a Magnetic Field: Examples and Applications	783
The Hall Effect	787
Magnetic Force on a Current-Carrying Conductor	790
Torque on a Current Loop: Motors and Meters	792
Magnetic Fields Produced by Currents: Ampere's Law	794
Magnetic Force between Two Parallel Conductors	798
More Applications of Magnetism	799
<b>23 Electromagnetic Induction, AC Circuits, and Electrical Technologies</b>	<b>813</b>
Induced Emf and Magnetic Flux	814
Faraday's Law of Induction: Lenz's Law	816
Motional Emf	818
Eddy Currents and Magnetic Damping	821
Electric Generators	824
Back Emf	827
Transformers	827
Electrical Safety: Systems and Devices	831
Inductance	835
RL Circuits	838
Reactance, Inductive and Capacitive	840
RLC Series AC Circuits	843
<b>24 Electromagnetic Waves</b>	<b>861</b>
Maxwell's Equations: Electromagnetic Waves Predicted and Observed	862
Production of Electromagnetic Waves	864
The Electromagnetic Spectrum	866
Energy in Electromagnetic Waves	877
<b>25 Geometric Optics</b>	<b>887</b>
The Ray Aspect of Light	888
The Law of Reflection	889
The Law of Refraction	891
Total Internal Reflection	895
Dispersion: The Rainbow and Prisms	900
Image Formation by Lenses	904
Image Formation by Mirrors	915
<b>26 Vision and Optical Instruments</b>	<b>929</b>
Physics of the Eye	930
Vision Correction	933
Color and Color Vision	936
Microscopes	939
Telescopes	944
Aberrations	947
<b>27 Wave Optics</b>	<b>955</b>
The Wave Aspect of Light: Interference	956
Huygens's Principle: Diffraction	957
Young's Double Slit Experiment	959
Multiple Slit Diffraction	963

Single Slit Diffraction . . . . .	966
Limits of Resolution: The Rayleigh Criterion . . . . .	969
Thin Film Interference . . . . .	973
Polarization . . . . .	977
*Extended Topic* Microscopy Enhanced by the Wave Characteristics of Light . . . . .	984
<b>28 Special Relativity . . . . .</b>	<b>997</b>
Einstein's Postulates . . . . .	998
Simultaneity And Time Dilation . . . . .	1000
Length Contraction . . . . .	1005
Relativistic Addition of Velocities . . . . .	1009
Relativistic Momentum . . . . .	1013
Relativistic Energy . . . . .	1015
<b>29 Introduction to Quantum Physics . . . . .</b>	<b>1029</b>
Quantization of Energy . . . . .	1030
The Photoelectric Effect . . . . .	1032
Photon Energies and the Electromagnetic Spectrum . . . . .	1035
Photon Momentum . . . . .	1040
The Particle-Wave Duality . . . . .	1044
The Wave Nature of Matter . . . . .	1045
Probability: The Heisenberg Uncertainty Principle . . . . .	1048
The Particle-Wave Duality Reviewed . . . . .	1052
<b>30 Atomic Physics . . . . .</b>	<b>1061</b>
Discovery of the Atom . . . . .	1061
Discovery of the Parts of the Atom: Electrons and Nuclei . . . . .	1063
Bohr's Theory of the Hydrogen Atom . . . . .	1068
X Rays: Atomic Origins and Applications . . . . .	1074
Applications of Atomic Excitations and De-Excitations . . . . .	1079
The Wave Nature of Matter Causes Quantization . . . . .	1086
Patterns in Spectra Reveal More Quantization . . . . .	1088
Quantum Numbers and Rules . . . . .	1090
The Pauli Exclusion Principle . . . . .	1094
<b>31 Radioactivity and Nuclear Physics . . . . .</b>	<b>1111</b>
Nuclear Radioactivity . . . . .	1111
Radiation Detection and Detectors . . . . .	1115
Substructure of the Nucleus . . . . .	1117
Nuclear Decay and Conservation Laws . . . . .	1121
Half-Life and Activity . . . . .	1127
Binding Energy . . . . .	1132
Tunneling . . . . .	1136
<b>32 Medical Applications of Nuclear Physics . . . . .</b>	<b>1147</b>
Medical Imaging and Diagnostics . . . . .	1148
Biological Effects of Ionizing Radiation . . . . .	1151
Therapeutic Uses of Ionizing Radiation . . . . .	1156
Food Irradiation . . . . .	1158
Fusion . . . . .	1159
Fission . . . . .	1164
Nuclear Weapons . . . . .	1168
<b>33 Particle Physics . . . . .</b>	<b>1181</b>
The Yukawa Particle and the Heisenberg Uncertainty Principle Revisited . . . . .	1182
The Four Basic Forces . . . . .	1183
Accelerators Create Matter from Energy . . . . .	1185
Particles, Patterns, and Conservation Laws . . . . .	1188
Quarks: Is That All There Is? . . . . .	1192
GUTs: The Unification of Forces . . . . .	1199
<b>34 Frontiers of Physics . . . . .</b>	<b>1209</b>
Cosmology and Particle Physics . . . . .	1209
General Relativity and Quantum Gravity . . . . .	1216
Superstrings . . . . .	1221
Dark Matter and Closure . . . . .	1221
Complexity and Chaos . . . . .	1224
High-temperature Superconductors . . . . .	1225
Some Questions We Know to Ask . . . . .	1227
<b>A Atomic Masses . . . . .</b>	<b>1235</b>
<b>B Selected Radioactive Isotopes . . . . .</b>	<b>1241</b>
<b>C Useful Information . . . . .</b>	<b>1245</b>
<b>D Glossary of Key Symbols and Notation . . . . .</b>	<b>1251</b>
<b>Index . . . . .</b>	<b>1262</b>

# PREFACE

## About OpenStax College

OpenStax College is a non-profit organization committed to improving student access to quality learning materials. Our free textbooks are developed and peer-reviewed by educators to ensure they are readable, accurate, and meet the scope and sequence requirements of modern college courses. Unlike traditional textbooks, OpenStax College resources live online and are owned by the community of educators using them. Through our partnerships with companies and foundations committed to reducing costs for students, OpenStax College is working to improve access to higher education for all. OpenStax College is an initiative of Rice University and is made possible through the generous support of several philanthropic foundations.

## About This Book

Welcome to *College Physics*, an OpenStax College resource created with several goals in mind: accessibility, affordability, customization, and student engagement—all while encouraging learners toward high levels of learning. Instructors and students alike will find that this textbook offers a strong foundation in introductory physics, with algebra as a prerequisite. It is available for free online and in low-cost print and e-book editions.

To broaden access and encourage community curation, *College Physics* is “open source” licensed under a Creative Commons Attribution (CC-BY) license. Everyone is invited to submit examples, emerging research, and other feedback to enhance and strengthen the material and keep it current and relevant for today’s students. You can make suggestions by contacting us at [info@openstaxcollege.org](mailto:info@openstaxcollege.org). You can find the status of the project, as well as alternate versions, corrections, etc., on the StaxDash at <http://openstaxcollege.org> (<http://openstaxcollege.org>) .

## To the Student

This book is written for you. It is based on the teaching and research experience of numerous physicists and influenced by a strong recollection of their own struggles as students. After reading this book, we hope you see that physics is visible everywhere. Applications range from driving a car to launching a rocket, from a skater whirling on ice to a neutron star spinning in space, and from taking your temperature to taking a chest X-ray.

## To the Instructor

This text is intended for one-year introductory courses requiring algebra and some trigonometry, but no calculus. OpenStax College provides the essential supplemental resources at <http://openstaxcollege.org> ; however, we have pared down the number of supplements to keep costs low. *College Physics* can be easily customized for your course using Connexions (<http://cnx.org/content/col11406>). Simply select the content most relevant to your curriculum and create a textbook that speaks directly to the needs of your class.

## General Approach

*College Physics* is organized such that topics are introduced conceptually with a steady progression to precise definitions and analytical applications. The analytical aspect (problem solving) is tied back to the conceptual before moving on to another topic. Each introductory chapter, for example, opens with an engaging photograph relevant to the subject of the chapter and interesting applications that are easy for most students to visualize.

## Organization, Level, and Content

There is considerable latitude on the part of the instructor regarding the use, organization, level, and content of this book. By choosing the types of problems assigned, the instructor can determine the level of sophistication required of the student.

## Concepts and Calculations

The ability to calculate does not guarantee conceptual understanding. In order to unify conceptual, analytical, and calculation skills within the learning process, we have integrated Strategies and Discussions throughout the text.

## Modern Perspective

The chapters on modern physics are more complete than many other texts on the market, with an entire chapter devoted to medical applications of nuclear physics and another to particle physics. The final chapter of the text, “Frontiers of Physics,” is devoted to the most exciting endeavors in physics. It ends with a module titled “Some Questions We Know to Ask.”

## Supplements

Accompanying the main text are a **Student Solutions Manual and an Instructor Solutions Manual** (<http://openstaxcollege.org/textbooks/college-physics>) . The Student Solutions Manual provides worked-out solutions to select end-of-module Problems and Exercises. The Instructor Solutions Manual provides worked-out solutions to all Exercises.

## Features of OpenStax *College Physics*

The following briefly describes the special features of this text.

## Modularity

This textbook is organized on Connexions (<http://cnx.org>) as a collection of modules that can be rearranged and modified to suit the needs of a particular professor or class. That being said, modules often contain references to content in other modules, as most topics in physics cannot be discussed in isolation.

## Learning Objectives

Every module begins with a set of learning objectives. These objectives are designed to guide the instructor in deciding what content to include or assign, and to guide the student with respect to what he or she can expect to learn. After completing the module and end-of-module exercises, students should be able to demonstrate mastery of the learning objectives.

## Call-Outs

Key definitions, concepts, and equations are called out with a special design treatment. Call-outs are designed to catch readers' attention, to make it clear that a specific term, concept, or equation is particularly important, and to provide easy reference for a student reviewing content.

## Key Terms

Key terms are in bold and are followed by a definition in context. Definitions of key terms are also listed in the Glossary, which appears at the end of the module.

## Worked Examples

Worked examples have four distinct parts to promote both analytical and conceptual skills. Worked examples are introduced in words, always using some application that should be of interest. This is followed by a Strategy section that emphasizes the concepts involved and how solving the problem relates to those concepts. This is followed by the mathematical Solution and Discussion.

Many worked examples contain multiple-part problems to help the students learn how to approach normal situations, in which problems tend to have multiple parts. Finally, worked examples employ the techniques of the problem-solving strategies so that students can see how those strategies succeed in practice as well as in theory.

## Problem-Solving Strategies

Problem-solving strategies are first presented in a special section and subsequently appear at crucial points in the text where students can benefit most from them. Problem-solving strategies have a logical structure that is reinforced in the worked examples and supported in certain places by line drawings that illustrate various steps.

## Misconception Alerts

Students come to physics with preconceptions from everyday experiences and from previous courses. Some of these preconceptions are misconceptions, and many are very common among students and the general public. Some are inadvertently picked up through misunderstandings of lectures and texts. The Misconception Alerts feature is designed to point these out and correct them explicitly.

## Take-Home Investigations

Take Home Investigations provide the opportunity for students to apply or explore what they have learned with a hands-on activity.

## Things Great and Small

In these special topic essays, macroscopic phenomena (such as air pressure) are explained with submicroscopic phenomena (such as atoms bouncing off walls). These essays support the modern perspective by describing aspects of modern physics before they are formally treated in later chapters. Connections are also made between apparently disparate phenomena.

## Simulations

Where applicable, students are directed to the interactive PHeT physics simulations developed by the University of Colorado (<http://phet.colorado.edu> (<http://phet.colorado.edu>)). There they can further explore the physics concepts they have learned about in the module.

## Summary

Module summaries are thorough and functional and present all important definitions and equations. Students are able to find the definitions of all terms and symbols as well as their physical relationships. The structure of the summary makes plain the fundamental principles of the module or collection and serves as a useful study guide.

## Glossary

At the end of every module or chapter is a glossary containing definitions of all of the key terms in the module or chapter.

## End-of-Module Problems

At the end of every chapter is a set of Conceptual Questions and/or skills-based Problems & Exercises. Conceptual Questions challenge students' ability to explain what they have learned conceptually, independent of the mathematical details. Problems & Exercises challenge students to apply both concepts and skills to solve mathematical physics problems. Online, every other problem includes an answer that students can reveal immediately by clicking on a "Show Solution" button. Fully worked solutions to select problems are available in the Student Solutions Manual and the Teacher Solutions Manual.

In addition to traditional skills-based problems, there are three special types of end-of-module problems: Integrated Concept Problems, Unreasonable Results Problems, and Construct Your Own Problems. All of these problems are indicated with a subtitle preceding the problem.



## Integrated Concept Problems

In Integrated Concept Problems, students are asked to apply what they have learned about two or more concepts to arrive at a solution to a problem. These problems require a higher level of thinking because, before solving a problem, students have to recognize the combination of strategies required to solve it.

## Unreasonable Results

In Unreasonable Results Problems, students are challenged to not only apply concepts and skills to solve a problem, but also to analyze the answer with respect to how likely or realistic it really is. These problems contain a premise that produces an unreasonable answer and are designed to further emphasize that properly applied physics must describe nature accurately and is not simply the process of solving equations.

## Construct Your Own Problem

These problems require students to construct the details of a problem, justify their starting assumptions, show specific steps in the problem's solution, and finally discuss the meaning of the result. These types of problems relate well to both conceptual and analytical aspects of physics, emphasizing that physics must describe nature. Often they involve an integration of topics from more than one chapter. Unlike other problems, solutions are not provided since there is no single correct answer. Instructors should feel free to direct students regarding the level and scope of their considerations. Whether the problem is solved and described correctly will depend on initial assumptions.

## Appendices

Appendix A: Atomic Masses

Appendix B: Selected Radioactive Isotopes

Appendix C: Useful Information

Appendix D: Glossary of Key Symbols and Notation

## Acknowledgements

This text is based on the work completed by Dr. Paul Peter Urone in collaboration with Roger Hinrichs, Kim Dirks, and Manjula Sharma. We would like to thank the authors as well as the numerous professors (a partial list follows) who have contributed their time and energy to review and provide feedback on the manuscript. Their input has been critical in maintaining the pedagogical integrity and accuracy of the text.

## Senior Contributing Authors

Dr. Paul Peter Urone

Dr. Roger Hinrichs, State University of New York, College at Oswego

## Contributing Authors

Dr. Kim Dirks, University of Auckland, New Zealand

Dr. Manjula Sharma, University of Sydney, Australia

## Expert Reviewers

Erik Christensen, P.E, South Florida Community College

Dr. Eric Kincanon, Gonzaga University

Dr. Douglas Ingram, Texas Christian University

Lee H. LaRue, Paris Junior College

Dr. Marc Sher, College of William and Mary

Dr. Ulrich Zurcher, Cleveland State University

Dr. Matthew Adams, Crafton Hills College, San Bernardino Community College District

Dr. Chuck Pearson, Virginia Intermont College

## Our Partners

### WebAssign

Webassign is an independent online homework and assessment system that has been available commercially since 1998. WebAssign has recently begun to support the Open Education Resource community by creating a high quality online homework solution for selected open-source textbooks, available at an affordable price to students. These question collections include randomized values and variables, immediate feedback, links to the open-source textbook, and a variety of text-specific resources and tools; as well as the same level of rigorous coding and accuracy-checking as any commercially available online homework solution supporting traditionally available textbooks.

### Sapling Learning

Sapling Learning provides the most effective interactive homework and instruction that improve student learning outcomes for the problem-solving disciplines. They offer an enjoyable teaching and effective learning experience that is distinctive in three important ways:

- **Ease of Use:** Sapling Learning's easy to use interface keeps students engaged in problem-solving, not struggling with the software.
- **Targeted Instructional Content:** Sapling Learning increases student engagement and comprehension by delivering immediate feedback and targeted instructional content.
- **Unsurpassed Service and Support:** Sapling Learning makes teaching more enjoyable by providing a dedicated Masters or PhD level colleague to service instructors' unique needs throughout the course, including content customization.

