SIX IDEAS THAT SHAPED

PHYSICS

Unit N: The Laws of Physics Are Universal

Thomas A. **Moore**

WCB McGraw-Hill

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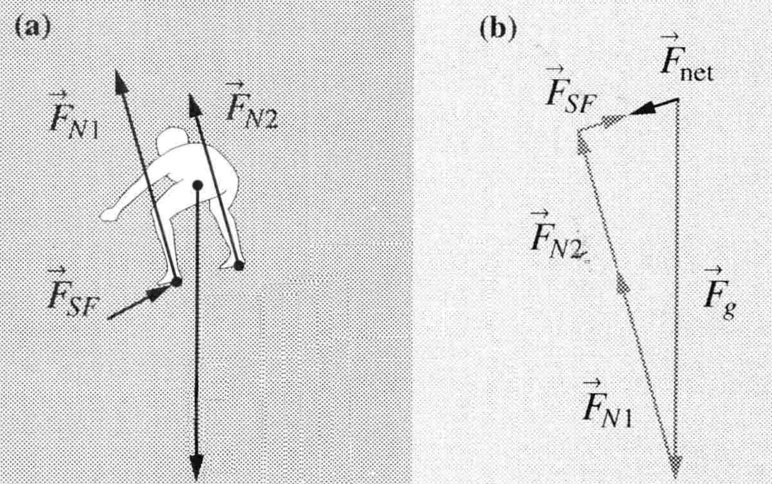

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SOME PHYSICAL CONSTANTS

Speed of Light	c	3.00×10^{8} m/s
Gravitational Constant	G	6.67×10^{-11} Nm²/kg²
Coulomb Constant	k	8.99×10^{9} Nm²/C²
Planck's Constant	h	6.63×10^{-34} Js
Boltzmann's Constant	k_B	1.38×10^{-23} J/K
Elementary charge	e	1.60×10^{-19} C
Electron Mass	m_e	9.11×10^{-31} kg
Proton Mass	m_p	1.67×10^{-27} kg
Neutron Mass	m_n	1.68×10^{-27} kg

COMMONLY-USED PHYSICAL DATA:

Gravitational Field Strength g	$9.80\ J{\cdot}kg^{-1}{\cdot}m^{-1} = 9.80\ m/s^2$
Density of Water	$1000.0\ kg/m^3 = 1\ g/cm^3$ *
Density of Air	$1.2\ kg/m^3$ *

* at normal pressure, 20°C

STANDARD METRIC PREFIXES

For Powers of Ten

Power	Prefix	Symbol
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

USEFUL CONVERSION FACTORS

1 meter = 1 m = 100 cm = 39.4 inches = 3.28 ft
1 mile = 1 mi = 1609 m = 1.609 km = 5280 ft
1 inch = 2.54 cm
1 light-year = 1 ly = 9.46 Pm = 0.946×10^{16} m

1 hour = 1 h = 60 min = 3600 s
1 day = 1 d = 24 h = 86.4 ks = 86,400 s
1 year = 1 y = 365.25 d = 31.6 Ms = 3.16×10^{7} s

1 J = 1 kg·m²/s² = 0.239 cal
1 kWh = 3.6 MJ

1.0 rad = 57.3° = 0.1592 rev

1 m/s = 2.24 mi/h
1 mi/h = 1.61 km/h
1 ft³ = 0.02832 m³
1 gallon = 1 gal = 3.79×10^{-3} m³ ≈ 3.8 kg H_2O

1 N = 1 kg·m/s² = 1 J/m = 0.225 lb
1 lb = 4.45 N
weight of 1-kg object near earth = 9.8 N = 2.2 lbs

1 W = 1 J/s
1 horsepower = 1 hp = 746 W

1 rev = 360° = 2π rad = 6.28 radians

USEFUL ASTRONOMICAL DATA

1 AU = mean distance from earth to sun = 1.50×10^{11} m

	Mass	Radius	Mean Orbital Radius	Orbital Period	Eccentricity
Sun	1.99×10^{30} kg	696,000 km	- - -	- - -	- - -
Moon	7.36×10^{22} kg	1740 km	384,000 km	27.3 days	0.055
Mercury	0.0558 M_E	2439 km	0.387 AU	0.241 y	0.206
Venus	0.815 M_E	6060 km	0.723 AU	0.615 y	0.007
Earth	5.98×10^{24} kg ≡ M_E	6380 km	1.000 AU	1.000 y	0.017
Mars	0.107 M_E	3370 km	1.524 AU	1.88 y	0.093
Jupiter	318 M_E	69,900 km	5.203 AU	11.9 y	0.048
Saturn	95.1 M_E	58,500 km	9.539 AU	29.5 y	0.056
Uranus	14.5 M_E	23,300 km	19.182 AU	84.0 y	0.047
Neptune	17.2 M_E	22,100 km	30.058 AU	165 y	0.009
Pluto/Charon	0.0025 M_E	3500/1800 km	39.785 AU	248 y	0.254
Ceres (asteroid)	1.2×10^{21} kg	500 km	2.768 AU	4.61 y	0.077
Halley's comet	1.2×10^{14} kg	≈ 7 km	17.94 AU	76.0 y	0.967

(Based mostly on data in D. Halliday, R. Resnick, *Fundamentals of Physics,* 3/e, New York:Wiley, p. A6.)

SYMBOLS AND THEIR MEANINGS

$=$	is equal to
$\neq$	is not equal to
$\approx$	is approximately equal to
$>$	is greater than
$<$	is less than
$>>$	is much greater than
$<<$	is much less than
$\equiv$	is defined to be
$\propto$	is proportional to
$\Rightarrow$	implies or therefore
$\int$	integral
∞	infinity
$\cdot$	indicates dot product OR product of units
$\times$	indicates cross product or multiplication by a power of 10
i.e.	*id est* "that is"
e.g.	*exempli gratia* "for example"
etc.	*etcetera* "and so on"
Q.E.D.	*quod erat demonstrandum* "which was to be demonstrated"
$\lvert x \rvert$	absolute value of x
mag()	magnitude of a vector
$\int$	indicates an integral
$'$	indicates a quantity measured in the S′ frame
$\vec{\beta}$	velocity of one frame relative to another
δ	phase constant
Δ	(as a prefix) a largish change in the variable whose symbol follows
Δt	(as a subscript) signifies *average* velocity or acceleration over the interval Δt
ε	orbital eccentricity
θ, ϕ, ψ	angles OR phase constants
$\hat{\theta}$	unit vector in the direction perpendicular to $\hat{r}$
μ_s, μ_k	static and kinetic coefficients of friction
ρ	mass density
$\vec{\tau}$	torque
$\vec{\omega}$	angular velocity
ω	magnitude of angular velocity OR phase rate
$\vec{a}$	acceleration
a	magnitude of $\vec{a}$ OR an arbitrary constant OR the semimajor axis of an elliptical orbit
A	area OR amplitude of an oscillation
$\vec{A}$	acceleration of one frame relative to another
AU	astronomical unit, a unit of distance
b	scalar constant OR unitless variable
c	speed of light OR an arbitrary constant
C	drag coefficient OR an arbitrary constant
C	(not italic) coulomb, the SI unit of charge
CM	(not italic, often as a subscript) center of mass
d	(as a prefix) tiny change in the variable whose symbol follows
$đ$	(as a prefix) one contribution to a tiny change in the variable following
$đ\vec{p}$	tiny momentum transfer
$đK$	tiny energy transfer
d, D	distance
e	charge on a proton OR exponential function
$f()$	function of whatever is in ()
$F()$	antiderivative of f()
$\vec{F}$	force
$\vec{F}_g$	gravitational force (weight)
$\vec{F}_N$	normal force
$\vec{F}_{SF}$	static friction (sticking) force
$\vec{F}_{KF}$	kinetic (sliding) friction force
$\vec{F}_D, \vec{F}_L$	drag force, lift force
$\vec{F}_{Th}, \vec{F}_B$	thrust force, buoyant force
$\vec{F}_{Sp}$	spring force
$\vec{F}_T$	tension force
$\vec{g}$	gravitational field vector
g	gravitational field strength = mag($\vec{g}$)
G	the universal gravitational constant
h	height
i	(as a subscript) means *initial* OR represents an index in a sum
I	moment of inertia
J	(not italic) joule, the SI unit of energy
k	the Coulomb constant
k_s	a spring (stiffness) constant
K	kinetic energy (also KE)
$\vec{L}$	angular momentum
L	length OR magnitude of angular momentum
m	mass
M	mass (usually of a system or large object)
m	(not italic) meter, a unit of distance
n	an arbitrary or unknown integer
N	number of particles in a system
N	(not italic) newton, the SI unit of force
0	(as a subscript) value of the attached variable at time $t = 0$ OR some other original value
O	the origin of a reference frame
$\vec{p}$	momentum
q	electrical charge OR unitless variable
$\vec{q}$	arbitrary vector
$\vec{r}$	a position vector
r	a radius or separation or mag($\vec{r}$)
$\hat{r}$	unit vector in the radial direction
R	a radius (often the fixed outer radius of some object, or a radius distinct from r)
$\vec{R}$	position of one frame relative to another
s	an arclength
t	time
T	period OR constant with units of time
u	$\equiv 1/r$ OR arbitrary and/or unitless variable
$\vec{v}$	velocity [speed $\equiv$ mag($\vec{v}$) $= v$]
$v_\perp$	component of $\vec{v}$ in the $\hat{\theta}$ direction
V	potential energy (also PE)
$\vec{w}, \hat{w}$	arbitrary vector, arbitrary unit vector
x, y, z	position coordinates
x, y, z	(as subscripts) indicates a component of a vector quantity
x-, y-, z-	(as prefixes) indicates a component of a vector quantity

For Brittany,
whose intuitive understanding of newtonian mechanics is part of what makes her awesome.

PREFACE

1. INTRODUCTION

Opening comments about this preliminary edition

This volume is one of six that together comprise the PRELIMINARY EDITION of the text materials for *Six Ideas That Shaped Physics,* a fundamentally new approach to the two- or three-semester calculus-based introductory physics course. This course is still very much a work in progress. We are publishing these volumes in preliminary form so that we can broaden the base of institutions using the course and gather the feedback that we need to better polish both the course and its supporting texts for a formal first edition in a few years. Though we have worked very hard to remove as many of the errors and rough edges as possible for this edition, we would greatly appreciate your help in reporting any errors that remain and offering your suggestions for improvement. I will tell you how you can contact us in a section near the end of this preface.

Much of this preface discusses features and issues that are common to all six volumes of the *Six Ideas* course. For comments about this specific unit and how it relates to the others, see section 7.

The course's roots in the Introductory University Physics Project

Six Ideas That Shaped Physics was created in response to a call for innovative curricula offered by the Introductory University Physics Project (IUPP), which subsequently supported its early development. IUPP officially tested very early versions of the course at University of Minnesota during 1991/92 and at Amherst and Smith Colleges during 1992/93. In its present form, the course represents the culmination of over eight years of development, testing, and evaluation at Pomona College, Smith College, Amherst College, St. Lawrence University, Beloit College, Hope College, UC-Davis, and other institutions.

The three basic principles of the IUPP project

We designed this course to be consistent with the three basic principles articulated by the IUPP steering committee in its call for model curricula:

1. **The pace of the course should be reduced** so that a broader range of students can achieve an acceptable level of competence and satisfaction.
2. **There should be more 20th-century physics** to better show students what physics is like at the present.
3. **The course should use one or more "story lines"** to help organize the ideas and motivate student interest.

My additional working principles

The design of *Six Ideas* was also strongly driven by two other principles:

4. **The course should seek to embrace the best of what educational research has taught us** about conceptual and structural problems with the standard course.
5. **The course should stake out a middle ground** between the standard introductory course and exciting but radical courses that require substantial investments in infrastructure and/or training. This course should be useful in fairly standard environments and should be relatively easy for teachers to understand and adopt.

A summary of the course's distinctive features

In its present form, *Six Ideas* course consists of a set of six textbooks (one for each "idea"), a detailed instructor's guide, and a few computer programs that support the course in crucial places. The texts have a variety of innovative features that are designed to (1) make them more clear and readable, (2) teach you *explicitly* about the processes of constructing models and solving complex problems, (3) confront well-known conceptual problems head-on, and (4) support the instructor in innovative uses of class time. The instructor's manual is much more detailed than is normal, offering detailed suggestions (based on many teacher-years of experience with the course at a variety of institutions) about how to structure the course and adapt it to various calendars and constituencies. The instructor's manual also offers a complete description of effective approaches to class time that emphasize active and collaborative learning over lecture (and yet can still be used in fairly large classes), supporting this with day-by-day lesson plans that make this approach much easier to understand and adopt.

In the remainder of this preface, I will look in more detail at the structure and content of the course and briefly explore *why* we have designed the various features of the course the way that we have.

2. GENERAL PHILOSOPHY OF THE COURSE

Problems with the traditional intro course

The current standard introductory physics course has a number of problems that have been documented in recent years. (1) There is so much material to "cover" in the standard course that students do not have time to develop a deep understanding of any part, and instructors do not have time to use classroom techniques that would help students really learn. (2) Even with all this material, the standard course, focused as it is on *classical* physics, does not show what physics is like *today*, and thus presents a skewed picture of the discipline to the 32 out of 33 students who will never take another physics course. (3) Most importantly, the standard introductory course generally fails to *teach physics*. Studies have shown that even students who earn high grades in a standard introductory physics course often cannot

1. apply basic physical principles to realistic situations,
2. solve realistic problems,
3. perceive or resolve contradictions involving their preconceptions, or
4. organize the ideas of physics hierarchically.

What students in such courses *do* effectively learn is how to solve highly contrived and patterned homework problems (either by searching for analogous examples in the text and then copying them without much understanding, or by doing a random search through the text for a formula that has the right variables.) The high pace of the standard course usually drives students to adopt these kinds of non-thinking behaviors even if they don't want to.

The goal: to help students become competent in using the skills listed above

The goal of *Six Ideas* is to help students achieve a meaningful level of competence in each of the four thinking skills listed above. We have rethought and restructured the course from the ground up so that students are goaded toward (and then rewarded for) behaviors that help them develop these skills. We have designed texts, exams, homework assignments, and activity-based class sessions to reinforce each other in keeping students focused on these goals.

The focus is more on skills than on specific content

While (mostly for practical reasons) the course does span the most important fields of physics, the emphasis is *not* particularly on "covering" material or providing background vocabulary for future study, but more on developing problem-solving, thinking, and modeling skills. Facts and formulas evaporate quickly (particularly for those 32 out of 33 that will take no more physics) but if we can develop students' abilities to think like a physicist in a variety of contexts, we have given them something they can use throughout their lives.

3. TOPICS EXPLORED IN THE COURSE

The six-unit structure

Six Ideas That Shaped Physics is divided into six units (normally offered three per semester). The purpose of each unit is to explore in depth a single idea that has changed the course of physics during the past three centuries. The list below describes each unit's letter name, its length (1 d = one day ≡ one 50-minute class session), the idea, and the corresponding area of physics.

First Semester (37 class days excluding test days):

Unit C	(14 d)	*Conservation Laws Constrain Interactions*	(conservation laws)
Unit N	(14 d)	*The Laws of Physics are Universal*	(forces and motion)
Unit R	(9 d)	*Physics is Frame-Independent*	(special relativity)

Second Semester (42 class days excluding test days):

Unit E	(17 d)	*Electromagnetic Fields are Dynamic*	(electrodynamics)
Unit Q	(16 d)	*Particles Behave Like Waves*	(basic quantum physics)
Unit T	(9 d)	*Some Processes are Irreversible*	(statistical physics)

(Note that the spring semester is assumed to be longer than fall semester. This is typically the case at Pomona and many other institutions, but one can adjust the length of the second semester to as few as 35 days by omitting parts of unit Q.)

Dividing the course into such units has a number of advantages. The core idea in each unit provides students with motivation and a sense of direction, and helps keep everyone focused. But the most important reason for this structure is that it makes clear to students that some ideas and principles in physics are more important than others, a theme emphasized throughout the course.

Comments about the non-standard order

The non-standard order of presentation has evolved in response to our observations in early trials. **[1]** Conservation laws are presented first not only because they really are more fundamental than the particular theories of mechanics considered later but also because we have consistently observed that students understand them better and can use them more flexibly than they can Newton's laws. It makes sense to have students *start* by studying very powerful and broadly applicable laws that they can also understand: this builds their confidence while developing thinking skills needed for understanding newtonian mechanics. This also delays the need for calculus. **[2]** Special relativity, which fits naturally into the first semester's focus on mechanics and conservation laws, also ends that semester with something both contemporary and compelling (student evaluations consistently rate this section very highly). **[3]** We found in previous trials that ending the second semester with the intellectually demanding material in unit Q was not wise: ending the course with Unit T (which is less demanding) and thus more practical during the end-of-year rush.

Options for adapting to a different calendar

The suggested order also offers a variety of options for adapting the course to other calendars and paces. One can teach these units in three 10-week quarters of two units each: note that the shortest units (R and T) are naturally paired with longest units (E and Q respectively) when the units are divided this way. While the first four units essentially provide a core curriculum that is difficult to change substantially, omitting either Unit Q or Unit T (or both) can create a gentler pace without loss of continuity (since Unit C includes some basic thermal physics, a version of the course omitting unit T still spans much of what is in a standard introductory course). We have also designed unit Q so that several of its major sections can be omitted if necessary.

Using the volumes alone or in different orders

Many of these volumes can also stand alone in an appropriate context. Units C and N are tightly interwoven, but with some care and in the appropriate context, these could be used separately. Unit R only requires a basic knowledge of mechanics. In addition to a typical background in mechanics, units E and Q require only a few very basic results from relativity, and Unit T requires only a very basic understanding of energy quantization. Other orders are also possible: while the first four units form a core curriculum that works best in the designed order, units Q and T might be exchanged, placed between volumes of the core sequence, or one or the other can be omitted.

Superficially, the course might seem to involve quite a bit *more* material than a standard introductory physics course, since substantial amounts of time are devoted to relativity and quantum physics. However, we have made substantial cuts in the material presented in the all sections of the course compared to a standard course. We made these cuts in two different ways.

The pace was reduced by cutting whole topics...

First, we have omitted entire topics, such as fluid mechanics, most of rotational mechanics, almost everything about sound, many electrical engineering topics, geometric optics, polarization, and so on. These cuts will no doubt be intolerable to some, but *something* has to go, and these topics did not fit as well as others into this particular course framework.

... and by streamlining the presentation of the rest

Our second approach was to simplify and streamline the presentation of topics we *do* discuss. A typical chapter in a standard textbook is crammed with a variety of interesting but tangential issues, applications, and other miscellaneous factons. The core idea of each *Six Ideas* unit provides an excellent filter for reducing the number density of factons: virtually everything that is not *essential* for developing that core idea has been eliminated. This greatly reduces the "conceptual noise" that students encounter, which helps them focus on learning the really important ideas.

Because of the conversational writing style adopted for the text, the total page count of the *Six Ideas* texts is actually similar to a standard text (about 1100 pages), but if you compare typical chapters discussing the same general material, you will find that the *density* of concepts in the *Six Ideas* text is much lower, leading to what I hope will be a more gentle perceived pace.

Choosing an appropriate pace

Even so, this text is *not* a "dumbed-down" version of a standard text. Instead of making the text dumber, I have tried very hard to challenge (and hopefully enable) students to become *smarter*. The design pace of this course (one chapter per day) is pretty challenging considering the sophistication of the material, and really represents a maximum pace for fairly well-prepared students at reasonably selective colleges and universities. However, I believe that the materials *can* be used at a much broader range of institutions and contexts at a lower pace (two chapters per three sessions, say, or one chapter per 75-minute class session). This means either cutting material or taking three semesters instead of two, but it can be done. The instructor's manual discusses how cuts might be made.

Part of the point of arranging the text in a "chapter-per-day" format is to bee clear about how the pace should be *limited*. Course designs that require covering *more* than one chapter per day should be strictly avoided: if there are too few days to cover the chapters at the design pace, than chapters will *have* to be cut.

4. FEATURES OF THE TEXT

The texts are designed to serve as students' primary source of new information

Studies have suggested that lectures are neither the most efficient nor most effective way to present expository material. One of my most important goals was to develop a text that could essentially replace the lecture as the primary *source* of information, freeing up class time for activities that help students *practice* using those ideas. I also wanted to create a text that not only presents the topics but goads students to develop model-building and problem-solving skills, helps them organize ideas hierarchically, encourages them to think qualitatively as well as quantitatively, and supports active learning both inside and outside of class.

A list of some of the texts' important features

In its current form, the text has a variety of features designed to address these needs, (many of which have evolved in response to early trials):

1. **The writing style is expansive and conversational**, making the text more suitable to be the primary way students learn new information.
2. **Each chapter corresponds to one (50-minute) class session**, which helps guide instructors in maintaining an appropriate pace.
3. **Each chapter begins with a unit map and an overview** that helps students see how the chapter fits into the general flow of the unit.
4. **Each chapter ends with a summary** that presents the most important ideas and arguments in a hierarchical outline format.
5. **Each chapter has a glossary** that summarizes technical terms, helping students realize that certain words have special meanings in physics.

6. **The book uses "user-friendly" notation and terminology** to help students keep ideas clear and avoid misleading connotations.
7. **Exercises embedded in the text** (with provided answers) help students actively engage the material as they prepare for class (providing an active alternative to examples).
8. **Wide outside margins** provide students with space for taking notes.
9. **Frequent *Physics Skills* and *Math Skills* sections** explicitly explore and summarize generally-applicable thinking skills.
10. **Problem-solving frameworks** (influenced by work by Alan van Heuvelan) help students learn good problem-solving habits.
11. **Two-minute problems** provide a tested and successful way to actively involve students during class and get feedback on how they are doing.
12. **Homework problems** are generally more qualitative than standard problems, and are organized according to the general thinking skills required.

5. ACTIVE LEARNING IN AND OUT OF CLASS

The *Six Ideas* texts are designed to support active learning both inside and outside the classroom setting. A properly designed course using these texts can provide to students a rich set of active-learning experiences.

Active learning using two-minute exercises

The *two-minute exercises* at the end of each chapter make it easy to devote at least part of each class session to active learning. These mostly conceptual questions do not generally require much (if any) calculation, but locating the correct answer does require careful thinking, a solid understanding of the material, and (often) an ability to apply concepts to realistic situations to answer correctly. Many explicitly test for typical student misconceptions, providing an opportunity to expose and correct these well-known stumbling blocks.

I often begin a class session by asking students to work in groups of two or three to find answers for a list of roughly three two-minute problems from the chapter that was assigned reading for that class session. After students have worked on these problems for some time, I ask them to show me their answers for each question in turn. The students hold up the back of the book facing me and point to the letter that they think is the correct answer. This gives me instant feedback on how well the students are doing, and provides me with both grist for further discussion and a sense where the students need the most help. On the other hand, students cannot see each others' answers easily, making them less likely to fear embarrassment (and I work very hard to be supportive).

Active demonstrations

Once everyone gets the hang of the process, it is easy to adapt other activities to this format. When I do a demonstration, I often make it more active by posing questions about what will happen, and asking students to respond using the letters. This helps everyone think more deeply about what the demonstration really shows and gets the students more invested in the outcome (and more impressed when the demonstration shows something unexpected).

The exercises support active reading

The in-text exercises and homework problems provide opportunities for active learning *outside* of class. The exercises challenge students to test their understanding of the material as they read it, helping them actively process the material and giving them instant feedback. They also provide a way to get students through derivations in a way that actively involves them in the process and yet "hides" the details so that the structure of the derivation is clearer. Finally, such exercises provide an active alternative to traditional examples: instead of simply displaying the example, the exercises encourage students to work through it.

The types of homework problems

The homework problems at the end of each chapter are organized into four types. ***Basic*** problems are closest to the type of problems found in standard texts: they are primarily for practicing the application of a single formula or concept in a straightforward manner and/or are closely analogous to examples in the text. ***Synthetic*** problems generally involve more realistic situations, require students to apply *several* concepts and/or formulas at once, involve creating or applying models, and/ or require more sophisticated reasoning. ***Rich-Context*** problems are synthetic problems generally cast in a narrative framework where either too much or too little information is given and/or a non-numerical question is posed (that nonetheless requires numerical work to answer). ***Advanced*** problems usually explore subtle theoretical issues or mathematical derivations beyond the level of the class: they are designed to challenge the very best students and/or remind instructors about how to handle subtle issues.

Collaborative recitation sessions

The rich-context problems are especially designed for collaborative work. Work by Heller and Hollenbaugh has shown that students solving standard problems rarely collaborate even when "working together", but that a well-written rich-context problem by its very open-ended nature calls forth a discussion of physical concepts, requiring students to work together to create useful models. I typically assign one such problem per week that students can work in a "recitation" section where can they work the problem in collaborative groups (instead of being lectured to by a TA).

The goal of the course is that the majority of students should ultimately be able to solve problems at the level of the *synthetic* problems in the book. Many of the rich-context problems are too difficult for individual students to solve easily, and the advanced problems are meant to be beyond the level of the class.

The way that a course is structured can determine its success

In early trials of *Six Ideas*, we learned that whether a course succeeds or fails depends very much the details of how the course is *structured*. This text is designed to more easily support a productive course structure, but careful work on the course design is still essential. For example, a "traditional" approach to assigning and grading homework can lead students to be frustrated (rather than challenged) by the richer-than-average homework problems in this text. Course structures can also either encourage or discourage students from getting the most out of class by preparing ahead of time. Exams can support or undermine the goals of the course. The instructor's manual explores these issues in much more depth and offers detailed guidance (based on our experience) about how design a course that gets the most out of what these books have to offer.

6. USE OF COMPUTERS

Using computers

The course, unlike some recent reform efforts, is *not* founded to a significant degree on the use of computers. Even so, a *few* computer programs are deployed in a few crucial places to support a particular line of argument in the text, and unit *T* in particular comes across significantly better when supported by a relatively small amount of computer work.

The most current versions of the computer programs supporting this course can be downloaded from my web-site or we will send them to you on request (see the contact information in section 8 below).

7. NOTES ABOUT UNIT *N*

The purpose and place of this unit in the course

This particular unit is primarily focused on Newton's second law and its application to both terrestrial and celestial physics. Its goal is to help students appreciate the power and breadth of the newtonian perspective as well as the historical importance of Newton's work.

This unit is structured on the premise that students have already studied unit *C*, and indeed it draws on ideas from almost all of the chapters of that unit. It in turn is needed as basic background for all of the other units in the course.

The unit's spiral structure

This unit is designed to teach newtonian mechanics using a "spiral learning" approach. The first five chapters provide a mostly qualitative introduction to the concepts and techniques of newtonian mechanics, while the remaining chapters explore quantitative applications of these ideas in depth. Instructors can help students get the most out of this approach by helping them see the connections between the earlier and later spirals through the given material.

Motion maps and trajectory diagram

An unusual feature of the first part of this text is the exploration of motion using *motion maps* and *trajectory diagrams*. Both of these tools are designed to deepen students' intuitive understanding of motion, and trajectory diagrams in particular are a powerful tool for qualitatively predicting an object's motion in advance of using mathematics. If students spend enough time practicing the use of both of these tools, their understanding of newtonian mechanics will become much deeper and more flexible.

I have also discussed the trajectory diagram in such depth because it provides an excellent conceptual basis for computer programs that calculate trajectories. I am in the process of trying to develop a user-friendly program that automates the trajectory-construction process. When this program is done, it could be used to in the latter part of the course to help students develop a more intuitive understanding of projectile, oscillatory, and planetary motion, and greatly enhance the range of applications that they can explore (for example, projectile or planetary motion with drag). Keep your eyes on the *Six Ideas* web site (see the next section for the URL) for news about this and other supporting computer programs.

Make sure students understand the material in chapter N9

The most difficult part of the unit for many students is the material on computing the radial and tangential components of acceleration in chapters N9 and N14. If chapter N14 is to make any sense to students (and this chapter *is* the capstone of the unit) special care and time should be taken to make sure that students understand the material in chapter N9. This material has been deliberately placed long before chapter N14 so that students will have sufficient time to absorb it before using it in chapter N14.

One can omit chapter N6 but not much else

Unit *N*, like unit *C*, is a mostly indivisible whole. Chapter N6 (which looks at torque and statics problems) could probably be omitted if cuts are absolutely necessary: it is not essential for anything else in the course. Chapters N14 and N8 also cover material that not needed in the rest of the course, but I would recommend against omitting these units: chapter N8 is very important for developing students' understanding of Newton's third law and how linked objects interact, and dropping chapter N14 would mean that students would not see the fulfillment of the unit's "great idea." In short, if cuts need to be made, start with chapter N6, but all of the other chapters have important roles to play.

Please see the instructor's manual for more detailed comments about this unit and suggestions about how to teach it effectively.

8. HOW TO COMMUNICATE SUGGESTIONS

Please help me make this a better text!

As I said at the beginning of this preface, this is a preliminary edition that represents a snapshot of work in progress. I would greatly appreciate your helping me make this a better text by telling me about errors and offering suggestions for improvement (words of support will be gratefully accepted too!). I will also try to answer your questions about the text, particularly if you are an instructor trying to use the text in a course.

The *Six Ideas* bulletin board

McGraw-Hill has set up an electronic bulletin board devoted to this text. This is the primary place where you can converse with me and/or other users of the text. Please post your comments, suggestions, criticisms, encouragement, error reports, and questions on this bulletin board. I will check it often and respond to whatever is posted there. The URL for this bulletin board is:

`http://mhhe.com/physsci/physical/moore`

The *Six Ideas* web site

Before you send in an error or ask a question, please check the error postings and/or FAQ list on my *Six Ideas* web site. The URL for this site is:

`http://pages.pomona.edu/~tmoore/sixideas.html`

Visiting this site will also allow you to read the latest information about the *Six Ideas* course and texts on this site, download the latest versions of the supporting computer software, and visit related sites. You can also reach me via e-mail at tmoore@pomona.edu.

How to get other volumes or ancillary materials

Please refer questions about obtaining copies of the texts and/or ancillary materials to your WCB/McGraw-Hill representative or as directed on the *Six Ideas* web-site.

9. APPRECIATION

Thanks!

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Thomas A. Moore
Claremont, California
November 25, 1997

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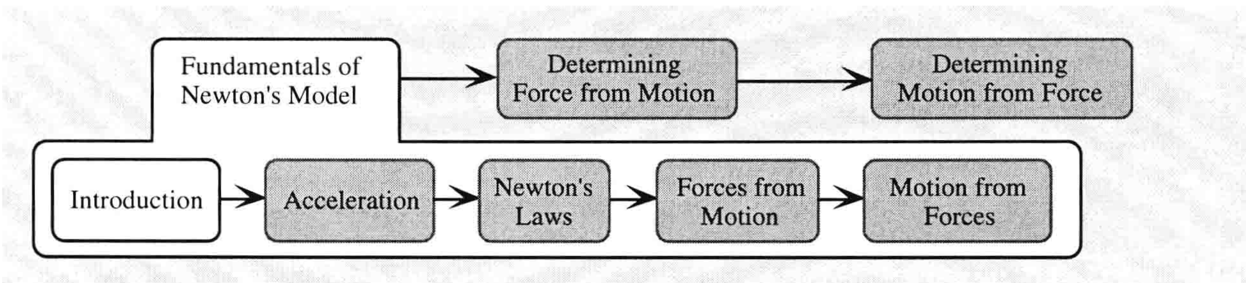
N1

INTRODUCTION



N1.1 OVERVIEW

In the last unit, we explored the constraints that the three great conservation laws (conservation of *linear momentum*, conservation of *energy*, and conservation of *angular momentum*) put on the behavior of systems of interacting objects. Part of the power of these laws is that we can apply them without knowing much about the detailed nature of the interactions involved or exactly how they act to modify the objects' motions.

Our task in this unit is to delve into the details. This is because our ultimate goal in this unit is to understand the **newtonian synthesis**: that is, how Newton's model of mechanics is able to explain celestial as well as terrestrial motion. In order to appreciate this, we *have* to understand exactly how interactions modify an object's motion. In this unit, then, we will sequentially develop the analysis skills we need to illuminate (first) terrestrial physics and (finally) celestial physics at the end of the unit.

This chapter starts the process by first setting the historical context for the newtonian synthesis (so that we can better understand its importance) and then introducing the basic principles of mathematical analysis of motion. Here is a summary of the sections in this chapter.

N1.2 *ARISTOTELIAN PHYSICS* describes the view of physics accepted by Western thinkers before Galileo, a theory that assumed a sharp distinction between the causes of celestial and terrestrial motion.

N1.3 *THE ARISTOTELIAN WORLD-VIEW CRUMBLES* describes how this perspective began to fall apart when confronted with new ideas and new observations in the late 1500s and early 1600s.

N1.4 *THE NEWTONIAN SYNTHESIS* explores the significance and impact of Newton's work in this context.

N1.5 *OVERVIEW OF UNIT N* describes the goals and organization of the unit and how we will explore the Newtonian synthesis.

N1.6 *THE TIME-DERIVATIVE OF A VECTOR* begins our exploration of the mathematics of motion by defining the time-derivative of a vector.

N1.7 *VELOCITY* applies this definition to formally and rigorously define what we mean by the *instantaneous velocity* of an object.

**** ***MATH SKILLS: DERIVATIVES*** reviews the definition of the derivative and various useful theorems (such as the sum and product rules).