Force, Motion, and Energy

Teacher's Guide and Resource Book

SAMPLER

PREFACE

The purpose of this *Teacher's Guide and Resource Book* is to provide you, the teacher, with the necessary background information to enable your students to get the most out of the *FM&E* course. To this end, you will find detailed suggestions for using reading sections, experiments, and problems in a variety of settings, as well as a general discussion of the content and pedagogy of the program. To explain the educational underpinnings of the course, we first present an Introduction that offers a broad perspective designed to introduce the course to those teaching it for the first time. The Introduction will provide a sound framework for the detailed suggestions that comprise the bulk of this *Guide*.

We hope that you will find the perforated, three-hole-punched format of this *Teacher's Guide and Resource Book* useful in developing and compiling your personal notes and class results.

Uri Haber-Schaim
Reed Cutting
H. Graden Kirksey
Harold A. Pratt
Robert D. Stair

INTRODUCTION TO *FM&E*

Key Principles

Even a casual perusal of the *FM&E* textbook reveals how different it is from other textbooks. As a teacher new to the course, you may wonder about the source of the many differences that you encounter. Most of the characteristic qualities of *FM&E* are the result of the consistent application of the following guidelines.

Having a clear set of objectives

The broad objective of *FM&E* can be summarized as the development of laboratory skills, reasoning skills (*e.g.*, the application of knowledge to new situations), and communication skills while gaining an understanding of the three terms that make up the title of the text: *Force, Motion, and Energy*. Our approach is selective. Rather than covering a great deal of ground in a superficial way, we concentrate on a few key topics on which students will be able to build in the future, without the need to "unlearn" things. This guideline had a profound effect on the construction of the sequence, as will be explained in The Structure of the Course.

Starting where the students are

FM&E relies on the fact that all students have had some everyday experience with pushes and pulls; time, distance, and speed ("fast," "slow"); and temperature. But

FM&E has no science-content prerequisites. In this program, all new ideas are based on concrete student experiences in the laboratory, and all new terms are introduced only *after* the need for them has been established. This approach avoids the association of science with a technical vocabulary that must be memorized and is unrelated to the students' own experience.

Giving the students the time they need

The application of this guideline negates the *a priori* establishment of required coverage. From the development of the preliminary edition through this edition, we have allotted the time for a given topic on the basis of field-testing. A topic was eliminated if we thought that the time could be utilized more productively. A corollary to these considerations is the conclusion that students are better served by studying the course thoroughly rather than rushing through it.

The Structure of the Course

In broad terms, the *FM&E* course divides naturally into three parts, which form a clear sequence. Chapter 1 introduces balanced forces acting along a line. Specifically, weight, the elastic force, the magnetic force, and friction are studied quantitatively, which leads to a discussion of Newton's third law. In Chapter 2, pressure is introduced, and attention shifts to forces exerted by liquids and gases. Chapter 3 brings in vectors to represent noncollinear forces and culminates with qualitative experimentation on the effects of forces on moving objects.

Chapter 4 covers motion, primarily motion at constant speed. The chapter emphasizes that an object can move at constant speed even though forces are acting on it, provided that the net force is zero. From the motion of objects at constant speed, we proceed to the motion of waves in homogeneous media (Chapter 5). The relations between time, distance, and speed developed in Chapter 4 are now applied to both longitudinal and transverse waves.

Since thermal energy is used in this course as a measure for other forms of energy, a thorough introduction to thermal energy is provided in Chapter 6. In the process, specific heat and heat of fusion are introduced experimentally. Finally, in Chapter 7, concepts studied in the prior chapters — namely, forces, change in position, and motion at constant speed — lead to an understanding of potential and kinetic energy and the law of conservation of energy.

In addition to this thematic progression, skills that are introduced at the beginning of the course are applied throughout. Key examples include the idea of proportionality, which is developed in Chapter 1, and the use of histograms as a way of summarizing class data and reaching conclusions.

The structure outlined above is best described by the annotated table of contents beginning on the next page.

Annotated Table of Contents

Chapter 1 Forces	
1.1 Introduction 1.2 **Experiment**: Weight and the Spring Scale 1.3 Hooke's Law: Proportionality 1.4 **Experiment**: The Magnetic Force 1.5 **Experiment**: Sliding Friction 1.6 Friction and Weight 1.7 Newton's Third Law	Although "force" is a common word, its use in science is specific and quantitative. This idea is made clear in the brief introduction and in Experiment 1.2, in which a spring is calibrated in arbitrary weight-units to motivate the introduction of the newton scale. Extension of the spring as a function of weight (Experiment 1.2) is used as an example of proportionality, a concept that recurs throughout the course (Section 1.3). Further development of this topic, as well as reinforcement of graphing skills, appear in Appendixes 1 and 2. Experiment 1.4, in which the magnetic force between two magnets is measured as a function of the separation between the closest poles, introduces the idea of dependence of a force on distance. In recognition of the prominent role that the force of friction plays in daily life, we show that friction does not act on an object at rest unless there is also another force acting on the object. Students investigate the minimum force needed to keep a body moving under a variety of conditions (Experiment 1.5). Taken together with Section 1.6, this experiment makes it evident that friction depends on weight, *not* weight per unit area, providing a transition to the next chapter. Finally, Newton's third law is discussed for static situations.
Chapter 2 Pressure	
2.1 Weight and Mass 2.2 **Experiment**: Mass, Volume, and Density 2.3 Force and Pressure 2.4 **Experiment**: Another Type of Balance	Later in the course, both weight and mass will be needed, so we now introduce the proportionality constant (*g*) between them. Since mass, especially for liquids, is often expressed as a product of density and volume, we introduce this relationship here and use it extensively in the rest of the chapter, as well as in later chapters (Experiment 2.2). Students often confuse force and pressure. This

2.5 Pressure in Liquids 2.6 The Buoyant Force 2.7 **Experiment**: Testing a Prediction 2.8 Atmospheric Pressure	chapter provides them with the opportunity to work with both concepts (Experiment 2.4). We demonstrate the dependence of pressure on depth and the independence of pressure on direction in liquids (Section 2.5) and use these ideas to derive the buoyant force (Section 2.6). Students then test the results experimentally (Experiment 2.7). In Section 2.8, the pressure in liquids is compared with the pressure in gases.
Chapter 3 Forces Acting in Different Directions	
3.1 Representing Forces 3.2 **Experiment**: Combining Forces 3.3 The Net Force 3.4 Forces and Their Components 3.5 **Experiment**: Forces Acting on Moving Bodies 3.6 Forces and Motion: A Summary	Through experience, students know that the effect of a force depends on its strength and direction. Since restricting force to a single line is quite artificial, we introduce vectors to represent forces. The usefulness of this representation is made clear in Experiment 3.2, in which the students balance the forces exerted by three spring scales in a plane. The relationship between the effect of two forces and a third force that balances them is discussed in Section 3.3. A common misconception is that bodies move in the direction of the force acting on them. Students find out that this is not the case by blowing in various directions on a moving frictionless puck (Experiment 3.5). The chapter concludes with a review that includes the formulation of Newton's first law.
Chapter 4 Distance, Time, and Speed	
4.1 Introduction to Black Boxes 4.2 **Experiment**: The Motion Detector — Measuring Distance 4.3 **Experiment**: The Motion Detector — Motion Graphs 4.4 Distance, Time, and Average Speed 4.5 **Experiment**: Terminal Speed 4.6 Working with Distance, Time, and Constant Speed	The traditional way of teaching kinematics (displacement → velocity → acceleration) is difficult even for high-school students. We consider it inappropriate at the level of this course. Instead, we work extensively with distance, time, and speed in the context of real-life situations. Our preferred way of introducing motion is with a motion detector and the students doing the moving (Sections 4.2 and 4.3). Section 4.4 introduces constant speed as an average speed that is the same in all intervals. A coffee filter dropped over a motion detector provides an example in which balanced forces produce motion at constant speed (Experiment

	4.5). Combining the idea of constant speed with the ideas of distance and time provides the tools for solving a variety of problems using common units for these quantities (Section 4.6).
Chapter 5 Waves	
5.1 Sound: Something Else that Moves 5.2 Visualizing Sound: Longitudinal Waves 5.3 **Experiment**: The Speed of Sound 5.4 Waves in Gases and Liquids 5.5 **Experiment**: Transverse Waves on a Coil Spring 5.6 Waves in Solids 5.7 Internet Activity: Locating an Earthquake	Waves are of fundamental importance in science and provide examples for a variety of motions at constant speed. Their motion is fundamentally different from the motion of material objects (Section 5.1). To visualize sound waves, we generate longitudinal waves on a coil spring (Section 5.2). The speed of sound is measured in an outdoor experiment using simple equipment (Experiment 5.3). The coil spring is used to introduce transverse waves (Section 5.5). The discussion of waves in solids (transverse and longitudinal) is then applied to earthquakes (Sections 5.6 and 5.7).
Chapter 6 Heating and Cooling	
6.1 Introduction 6.2 **Experiment:** Mixing Warm and Cool Water 6.3 A Unit of Energy: The Joule 6.4 **Experiment:** Cooling a Warm Solid in Cool Water 6.5 The Specific Heat of Different Substances 6.6 **Experiment:** Melting Ice 6.7 Heat of Fusion and Heat of Vaporization	The usefulness of the idea of energy stems from the convertibility of energy into different forms. All forms of energy can be associated with a change in temperature. In this program, we define a change in some phenomenon as a change in energy when the original change is associated with a change in temperature. Experiment 6.2 helps to emphasize the difference between temperature and thermal energy. The results of the experiments are generalized in Sections 6.3–6.5, where specific heat is introduced. Melting ice in a calorimeter leads into the ideas of heat of fusion and heat of evaporation (Experiment 6.6 and Section 6.7).
Chapter 7 Potential and Kinetic Energy	
7.1 **Experiment**: Heating Produced by	Gravitational potential energy is introduced through the use of a slowly falling weight to raise

a Slowly Falling Object 7.2 Gravitational Potential Energy 7.3 Elastic Potential Energy 7.4 Kinetic Energy 7.5 Kinetic Energy as a Function of Speed 7.6 **Experiment**: Free Fall 7.7 The Law of Conservation of Energy	the temperature of an aluminum cylinder. The dependence of the temperature rise on the weight of the falling body for a fixed distance is part of the experiment (Experiment 7.1); the dependence on the height is discussed in Section 7.2. The results are generalized in an end-of-chapter problem to show that the change in gravitational potential energy depends only on the change in height and *not* on the distance traveled along a slope. An experiment measuring changes in elastic potential energy is described in Section 7.3. The increase in temperature generated by stopping a wheel with a heavy rim is described in detail, leading to the definition of kinetic energy (Sections 7.4 and 7.5). Once both gravitational potential energy and kinetic energy have been defined, their conversion is studied in a free-fall experiment using the motion detector (Section 7.6). The chapter is summed up with a discussion of the law of conservation of energy.

Components of the Textbook

Reading Sections

Some sections of the textbook are designated as "Experiments" and serve as guides to your students in their laboratory work. The other numbered sections lay the groundwork for new concepts; relate the results of experiments to students' understanding of the nature of force, motion, and energy; or serve as introductions to or summaries of chapters. These sections are often brief, yet they are an integral part of the course. Disregarding the reading sections reduces the course to a succession of unrelated experiments.

Experience has shown that it is worthwhile to have students read some of these sections aloud in class and discuss them in detail. Students should be asked to summarize a section for the class or to present important ideas in their own words.

Homework Problems

The text contains a large selection of problems — some are easy, short, and confidence-building; some are more complex; and, finally, some go beyond the course and serve as an optional extension of the material. This *Guide* identifies the various types of problems so that you can decide which problems will be most suitable for your class.

The problems and questions found at the ends of numbered sections within chapters generally cover single concepts and are designed to reinforce ideas immediately after they are encountered in the text or the laboratory. These questions may help your students decide whether they understand the ideas in a section and are ready to go on.

The sets of problems labeled "For Review, Applications, and Extensions" ("RAEs" for short) located at the end of each chapter follow the order of presentation of material within the chapter. The RAEs are designed to extend the students' knowledge to more general applications of the chapter and, in some cases, provide additional practice with important ideas. Many of the RAEs can be assigned to individual students based on their needs and abilities. Thus, it is not necessary to assign the same problems to all students. In particular, you can use the harder problems as extra assignments for students who wish to deepen their understanding.

To derive the maximum benefit from the RAEs at the ends of the chapters, it is important to assign them when the subjects they deal with are being discussed in class. Call on your students to present their solutions to assigned problems and to defend them before the class. Many of the questions raised in the homework problems, as well as in the experiments, have more than one answer, depending on the assumptions a student makes. Do not be tempted to judge the students' answers with a simple "right" or "wrong." Instead, ask for the reasoning behind their answers. It is better to assign fewer problems and treat them in this way than to have the class do more and hand them in once a week simply to be graded. Assigning 50 to 80 percent of the problems has been found to be appropriate, depending on the number and length of class periods and the ability of your students. Since topics and techniques from the early chapters of the text are used throughout the year, we recommend that from time to time you assign one or two problems from earlier chapters that are relevant to the current topic.

The Themes for Short Essays provide an outlet for creative writing in the context of science, and are best used in cooperation with a language arts teacher, or in a writing laboratory. We recommend that students be given the opportunity to revise their essays at least once. Some teachers offer extra credit for essays.

Teacher Demonstrations

In several cases, the textbook describes experiments not done by the class, giving actual data obtained with equipment shown in the illustrations. Try to demonstrate as many of these experiments as possible, or ask teams of students to prepare and present the demonstrations.

Index

Teachers new to *FM&E* sometimes wonder about the absence of a glossary at the end of the text. The reason is simple: a glossary invites memorization by the students, and serves as a source for inappropriate quiz questions by teachers. We like to avoid both. The legitimate use of a glossary is well served by the extensive index.

The Role of Laboratory Work in This Course

Pivotal Role of Experiments

Our knowledge of physical science is the result of years of experimentation. No student can experience all the discoveries that have been made to date, but as much as possible, we should like him or her to learn physical science in the laboratory. Your students' ability to understand the discoveries of others rests on their having real experiences themselves. They profit most by making their own observations and drawing their own conclusions.

In this course, the laboratory work is an integral part of the text. Some of the significant conclusions your students arrive at in the laboratory do not appear explicitly in the accompanying text. In other words, it is assumed in many cases that students have found in the laboratory facts or laws on which subsequent sections of the text are based.

Providing Guidance

The laboratory instructions in the textbook provide a minimum of directions and, by raising questions, call students' attention to the important points in an experiment. Sometimes the answers to these questions merely require thought; at other times experimentation is needed. Your students must decide what to do. At the beginning of the course, some students may feel a little insecure with this type of laboratory work. They are likely to ask whether they have the right result. You must help them to realize that nature cannot be wrong; our job is to understand nature by measurement and interpretation. If students have not measured what they set out to measure, a discussion, rather than a yes-or-no answer, is most helpful.

Responding to Students' Questions

Your students will ask for answers, and will continue to ask for them if you give them. If you allow students to find their own answers, they will not only learn more but also gain confidence in their ability to make useful decisions. At first, this may seem difficult, but if, after listening to their questions, you respond a few times with answers such as, "How can you find out?" or "Try it." or "Look it up." or "You have to decide." or "Are you satisfied with the data?" your students will become resourceful.

Collecting Class Data

Experiments should be done at the time they are encountered in studying the text. In this way, your students are not likely to know what to expect. As they progress in the course, they learn to enjoy doing experiments whose results they do not know in advance, even though they realize that someone has faced and solved the same problem before them.

Experimental data are usually collected by individuals or by pairs of students working in the laboratory. The task of collecting sufficient data is simplified by having the members of the class share the workload. These data are then pooled, often in the form of tables, graphs, or histograms from which generalizations can be drawn. For example, suppose a student seeks to determine the heat of fusion of water (Experiment 6.6). He or she would have to make a number of determinations using different amounts of ice and requiring several days. A properly planned class experiment will provide in one period data on a dozen samples of different sizes, which can then be pooled in a "post-lab" that will help the whole class reach a conclusion. The class generalizations often lead the class back to the laboratory for further refinements or additional experiments.

In addition to simplifying the collection of data, the class effort provides a very useful forum for discussion of ideas and results. The give-and-take atmosphere is vital if students are to learn how knowledge is acquired. Through these discussions, students learn from each other as well as from the teacher.

Planning Laboratory Work

Since the course is centered on experimental work by the students, it is of the utmost importance that the specified equipment be on hand and easily accessible. Although a well-designed science laboratory always is an asset, this course can be taught successfully in a classroom with flat tables and a reasonable amount of storage space.

A fair fraction of a class period usually is lost in setting up equipment and taking it down. This fraction is considerably reduced if double periods can be arranged.

To assist you in planning and conducting the experiments, the *Guide* includes information on apparatus, expected duration of the experiment, necessary materials, and recommended procedure.

Your students usually should be able to do an experiment in a 45–50-minute class period; however, when this is not possible, the *Guide* indicates the best point at which to interrupt an experiment. In many of the experiments, the *Guide* also indicates the degree of precision you may reasonably expect.

Most of the experiments are designed to be performed by two students working together. In many experiments, one pair of hands is not enough to carry out the necessary manipulations, but more than two students working together can lead to confusion and wasted time.

There is some advantage in individual work in the laboratory; it forces every student to come to *FM&E* with the whole experiment and prevents one of the partners from becoming a mere note-taker. On the other hand, working in pairs gives the students more confidence in their work, and they can learn from each other by discussing their data. In short, they learn to work cooperatively. However, each student must keep his or her own notebook.

Safety Procedures

Since the best thing to do about accidents is to prevent them, the *FM&E* experiments are designed to minimize classroom hazards. It should be noted, however, that a potential hazard exists whenever students are working in a laboratory. This *Guide* includes a complete list of equipment and supplies and the minimum standard of quality (pages 00–00). Our experience has shown that the major cause of accidents is the improper use and handling of the materials. We, therefore, urge you to review and practice the following general safety procedures with your class.

- Be sure that you and your students follow all local and state fire and safety regulations.
- Where possible, utilize plastic or unbreakable containers for dispensing materials.
- Insist that your students wear safety glasses whenever these are included in the list of apparatus and materials for an experiment in this *Guide*. Be sure to wear them yourself when required.

Pre-Lab and Post-Lab Discussions

Importance of Discussion

One of the most important aspects of teaching this course is conducting a discussion of an experiment before the class attempts it (a "pre-lab") and then, after the completion of the experiment, reviewing it with the class and discussing the conclusions that may be drawn from it (a "post-lab").

Students do not automatically learn something simply by doing an experiment, even though they may have obtained very good results. In order to interpret the results and realize the implications of them, each student must understand why he or she is doing an experiment before starting it. In the pre-lab before each experiment, it is advisable to involve the students in the design of the experiment as much as possible. In this way, they develop a better understanding of the purpose of the experiment, the procedures they will follow, and the kind of data they will have to collect. The pre-lab provides an opportunity for students to exercise their imagination and ingenuity. It also provides an opportunity to identify the equipment needed and to review important safety procedures that are appropriate for the experiment.

Characteristics of the Pre-Lab Discussion

Raising questions and leading a class discussion during the pre-lab are effective ways to help the students understand the experiment and any new techniques required to carry it out. (Sometimes, as in the case of safety precautions, this is not advisable — you must simply tell them how to do something.)

Most experiments are designed to help answer a specific important, basic question. Once students understand the question clearly, there is no reason why they cannot share in the excitement of designing an experiment to find an answer.

Most of the experiments in *FM&E* are quantitative in nature and require careful recording of data, drawing of graphs, and calculating of results.

In your discussion of an experiment in the pre-lab, do not give away the expected results. (However, you do not have to pretend, with any class, that the results are not known.)

In most cases, before you conduct the pre-lab discussion, it is advisable to insist that your students read the instructions for the experiment given in the text and think about why and how it is to be done.

Pooling Data

As we have said, answering questions in many of the quantitative experiments in the course requires the collection of all the data for different conditions obtained by the whole class. Even when all the students do exactly the same experiment, they usually have time to take only one set of readings. Individual results vary, and only the pooling of the results of all stations in a post-lab will lead to useful conclusions.

Perhaps the best way to pool individual results is to draw a histogram showing the results of the entire class. Such a histogram shows how separately determined values cluster around the most probable value — something that is not shown by individual results or by an average value calculated from the data of the whole class. Examples of class histograms are given in the discussion of the results of experiments in which histograms are useful.

It is sometimes valuable to have the entire class repeat an experiment when the pooling of class results does not lead to a firm conclusion. In such cases, class discussion of possible errors in procedure or measurement will lead to better results when the class tries the experiment again. It is particularly important in such circumstances not to divulge the expected results; if you do, students who have come close to the expected result will lack the incentive to repeat the experiment.

Software for Histograms

As indicated at the end of the discussion of the post-lab, histograms are used throughout the program to display data collected by students as part of their laboratory work. Appendix 4 provides a short discussion of the procedures for drawing histograms. When students are first learning to use histograms, constructing one or two of them by hand is a useful exercise. Once students have mastered the basics, the tedious and time-consuming work of constructing, altering, and refining their histograms can be better done with the student edition of *KaleidaGraph* from Synergy Software.

KaleidaGraph is powerful, user-friendly software that allows students to quickly and easily generate and modify histograms using the same approach that is presented in the Appendix 4. Just as they do when constructing histograms manually, students using KaleidaGraph choose the appropriate bin size and reference value, and decide whether to place the reference value in the center of a bin or on the border between bins. Other available options include adding empty bins at the ends and selecting from a range of fonts and colors.

The student edition of *KaleidaGraph* is available in both Macintosh and Windows versions. Macintosh users will need at least a Macintosh Plus running System 7.0 or a later system with 2 MB RAM. Windows users will need a 386 or later processor running Windows 95, NT, or 3.1 and at least 6 MB RAM. Both Macintosh and Windows users will need at least a 10-MB hard disk.

Student Laboratory Notebooks

Good Notebook Practices

It is imperative that all students keep a notebook containing a legible and complete record of what they do at the time they do it. The value of a good notebook is that students can refer to it at a later time and reconstruct the experiment from the recorded data and observations.

Do not insist on neatness in notebooks. It will only drive your students to recording data on scraps of paper (easily lost) and copying the data into their notebooks later, a practice that should never be allowed.

Whether the notebook is written in ink or pencil is not important. It need not be a work of art; neatness and organization need only be sufficient to allow a student's experiment to be completely reconstructed. There is nothing wrong with abbreviations and marginal notes as afterthoughts as long as the description is clear. The goal is to produce a useful laboratory notebook, not a formal report.

Avoid the common practice of having students put their records in order under headings such as "Object of Experiment," "Apparatus," "Diagram of Apparatus," or "Procedure." This tends to replace thought with a concern for mechanical details. There is no reason why every student's write-up of a given experiment should have the same form. All the details should be clear enough if the text instructions (and the illustrations and their captions) are read in conjunction with the laboratory notebooks. However, if the procedure used differs from that in the text for any reason, such as a student-suggested change in procedure (approved by you!) or a change in apparatus used, then this change should be briefly noted in the students' notebooks.

Encourage imaginative students who wish to vary the procedure for sound reasons or to extend the experiment in order to answer additional questions (perhaps coming back in their free time to do so).

When checking students' notebooks, you should point out errors in spelling, grammar, and sentence structure, particularly if they contribute to a lack of clarity.

All measurements taken should be recorded with appropriate units and must include the name of what is being measured.

Recording and Organizing Data

Data in notebooks are obtained from one of two sources: (1) a direct measurement or (2) a calculation. If from the latter, the entry in the notebook should show the source of the calculated figure, unless it is obvious.

The arrangement of the data should be such that anyone who understands the experiment can quickly reconstruct it without any doubt as to the procedure followed, measurements made, or calculations performed. While there are many arrangements that will accomplish this, three are especially well-suited to this purpose:

- A sequential listing of the data, calculations, and observations.
- A table that contains these same elements, when appropriate.
- Answers to questions and a conclusion, if appropriate.

If the experiment is to be run only once, a listing of the steps taken, along with the data and calculations, is usually best.

If the experiment requires that the same procedures be repeated several times, arranging the data in a table is often convenient, since it makes it easy to compare the results of different runs.

Let your students decide in the pre-lab, or individually, the best format for recording data and calculations in each experiment.

Using the Bulleted Questions

Answers to the bulleted questions asked in the text, as well as class data and class conclusions reached in the post-lab, should also be included in the laboratory notebook. Recording the conclusions is essential, since they are often important for work later on and may not be explicitly stated in the text.

Introductory questions establish a basis or rationale for doing the experiment. The questions that follow can be answered only during or after the experiment. For example, in Experiment 6.2, Mixing Warm and Cool Water, students are asked, “What is the ratio of the decrease in temperature for the warm-water sample to the increase for the cool sample?” “How does your ratio compare with those of your classmates?” These questions, of course, require answers, which should include the observations that provided the answer.

Also, there are bulleted questions that require students to make observations that are necessary to their understanding of the experiment. In such cases, it is important that students answer the question in their laboratory notebooks, chronologically, at the time they make observations. Do not allow students to make a numbered list of answers to all the questions at the end of the experiment. Insist on self-contained answers that leave no doubt as to which question is being answered.

Reaching Conclusions

Since the conclusions reached in the post-lab usually are based on experimental data from the entire class, class data needed to support them should also be included in the notebook. This will also stress the need for having a large amount of supporting evidence before stating a generalization. The conclusion written in the notebook should be an accurate and complete statement of the generalization made by the class in the post-lab discussion.

Checking Students' Notebooks

Many students will have had no previous experience in keeping a laboratory notebook. Therefore, it is important that the first few write-ups of experiments be given immediate and careful attention. This can best be accomplished by glancing at students' notebooks, asking questions, and making suggestions while they are doing an experiment. The extent to which this can be done will depend on the experiment. For example, if a measurement is being made every 30 seconds, it would disrupt the work to question students about their notebooks. If possible, sit down with individual students out of class and carefully go over an experiment, asking them questions about the entries in their notebooks and making suggestions as to how they might correct deficiencies. If this is not possible, collect the notebooks and write suggestions for improvement in the margins. Then see how well the improvements are made.

Assessing Achievement

Focus on Progress

Achievement in this course manifests itself in many ways, some of which are not subject to quantitative measurement. Consider, for example, the student who, at the beginning of the year, is quite lost in the laboratory and finds it hard to make a move without explicit instructions from you. A few months later, you see the same student working independently and knowledgeably; the student has certainly progressed. Another tangible is the improvement shown in students' skill in communicating orally the results of their laboratory work or the reasoning behind the solution of a problem. Progress in these domains, although hard to gauge quantitatively, should certainly be considered in arriving at a student's grade.

It is good practice, in regard to evaluations that are subjective by nature, to reward and encourage students who make progress in these areas, but not to downgrade those who do not. Students are individuals with individual differences, and their work cannot all be judged on the same basis.

Managing the Paperwork

Your paperwork in teaching this course need not be a burden if you are selective in what you read and mark. It is unnecessary and, in fact, impossible to read and correct every detail of all questions and RAEs that students do and all the experiments in their laboratory notebooks. Read only a few notebooks and homework papers at a time. When you do correct students' written work, it is important to do a thorough job. Only detailed and serious comments will win your students' respect. Be sure to check from time to time to see whether students have heeded your suggestions.

You can do much of the work of evaluating laboratory skills by checking your students' laboratory notebooks and their handling of different techniques as you move around the laboratory observing, questioning, and helping them (only when they really need help!).

Using the Assessment Package

To help you to determine your students' overall comprehension of the course and their ability to apply their acquired knowledge to new situations, we have developed a comprehensive Assessment Package. The package covers the entire course and is consistent with its objectives. There is a set of seven chapter tests, consisting of multiple-choice questions and essay questions. In addition, there is a set of lab tests. For details and specific suggestions on the use of the tests see the preface to the Assessment Package.

We have found that it is time-consuming to generate high-quality questions in the spirit of the *FM&E* course. If you wish to write questions, be sure that you put the emphasis on the broad topics that are stressed in the text and in the laboratory experiments. Students quickly realize that if they cram, they can score high grades on tests that rely heavily on memory and recall. "Open book" and "open lab" tests can be used to advantage in this course. Appropriateness for "open book" tests makes a good criterion for assessing any questions you write.

Assigning Grades

This course is definitely not suited to a straight averaging of all grades at the end of the year. Combining the averages of all seven *FM&E* multiple-choice tests, laboratory tests, and essay tests, and the laboratory-notebook grades (if you grade them), does not give a useful result. Rather than being made up of nearly independent "units," the course develops throughout the year as a series of closely and logically connected steps. The later parts of the course are built on the foundations laid in the earlier parts in such a way that most concepts, once introduced, keep reappearing throughout the course. The Epilogue of the student text may help you make a judgment of your students' achievement.

In reviewing your students' laboratory notebooks, RAEs' solutions, and oral presentations, you should, as mentioned, point out errors in spelling, grammar, and sentence structure, particularly if they interfere with clarity. However, in assigning grades, it is best to give no weight to such errors *per se,* but only to whatever lack of clarity results.

The Individual in the Class

It probably has become clear from what has been said so far in the Introduction that the *FM&E* course offers a wide variety of experiences to the individual while providing him or her with the benefits of interacting with the class as a whole. However, for the sake of emphasis, it is worthwhile to summarize the various ways in which you can personalize your instruction.

These ways of personalizing your relations with your students will serve individual needs while making full use of the class as a learning community. We feel that this approach answers the needs of the individual far better than letting individual students go at their own pace through the *same* material to the *same* depth.

In the Laboratory

Once the general purpose of an experiment is established in the pre-lab and the class begins to work, you can divide your time among the students according to their individual needs. Spend little time with those who are well on their way. Help, with a few leading questions, those who are encountering difficulties. Most experiments are open-ended; that is, there is always something useful to do for those who have finished the minimum assignment ahead of the others. Encourage them to go on.

Individual Contributions to Class Discussions

Every class has its extroverts and its introverts. Since being able to communicate ideas is an important goal of this course, call on students selectively to give those who need it more opportunity to present their solutions to problems or the results of their experiments to the class.

Accommodating Individual Interests

The degree and direction of interest that individual students have in the course will vary. Permit some of them to concentrate on the qualitative, and treat lightly the abstract ideas and the mathematical details. On the other hand, permit others to go into greater depth. Challenge them with harder RAEs. Let them help you in setting up class demonstrations and in teaching their peers.

Scheduling the Course

The most appropriate speed with which to proceed in the course varies over a wide range and depends on the ability of the students, the size of the class, and the number and length of class periods. Therefore, the overall schedule suggested here, which includes two periods for each chapter test but does not include the laboratory tests, should be regarded as a very general framework.

Chapter	Periods
1	11
2	13
3	11
4	9
5	9

6	11
7	14

A more detailed schedule appears at the beginning of each chapter discussion in this *Guide*. These detailed schedules also should be used for general orientation only.

RELATIONSHIP OF *FORCE, MOTION, & ENERGY* TO *INTRODUCTORY PHYSICAL SCIENCE*

If you are interested in providing a comprehensive course in physical science that meets the requirements of the *National Science Education Standards* and most state standards, then several possibilities are available to you that utilize both *Force, Motion, and Energy* (*FM&E*) and *Introductory Physical Science (IPS*). Three possibilities are outline below.

***FM&E* as a Stand-Alone Course**	***FM&E* before *IPS***	***FM&E* after *IPS***	***FM&E* and *IPS* as a 3-Semester Course**
FM&E Chapter 1 — Forces	*FM&E* Chapter 1 — Forces	*IPS* Chapter 1 — Volume and Mass	*FM&E* Chapter 1 — Forces
FM&E Chapter 2 — Pressure	*FM&E* Chapter 2 — Pressure	*IPS* Chapter 2 — Mass Changes in Closed Systems	*FM&E* Chapter 2 — Pressure
FM&E Chapter 3 — Forces Acting in Different Directions	*FM&E* Chapter 3 — Forces Acting in Different Directions	*IPS* Chapter 3 — Characteristic Properties	*FM&E* Chapter 3 — Forces Acting in Different Directions
FM&E Chapter 4 — Distance, Time, and Speed	*FM&E* Chapter 4 — Distance, Time, and Speed	*IPS* Chapter 4 — Solubility	*FM&E* Chapter 4 – Distance, Time, and Speed
FM&E Chapter 5 — Waves	*FM&E* Chapter 5 — Waves	*IPS* Chapter 5 — Separation of Mixtures	*FM&E* Chapter 5 — Waves
FM&E Chapter 6 — Heating and Cooling	*FM&E* Chapter 6 — Heating and Cooling	*IPS* Chapter 6 — Compounds and Elements	*FM&E* Chapter 6 — Heating and Cooling
FM&E Chapter 7 — Potential Energy and Kinetic Energy	*FM&E* Chapter 7 — Potential Energy and Kinetic Energy	*FM&E* Chapter 1 — Forces	*FM&E* Chapter 7 — Potential Energy and Kinetic Energy
Other topics related to life science and earth science standards	*IPS* Chapter 1* — Volume and Mass	*FM&E* Chapter 2**** — Pressure	*IPS* Chapter 1* — Volume and Mass
	IPS Chapter 2** — Mass Changes in Closed Systems	*FM&E* Chapter 3 — Forces Acting in Different Directions	*IPS* Chapter 2** — Mass Changes in Closed Systems
	IPS Chapter 3*** — Characteristic Properties	*FM&E* Chapter 4 — Distance, Time, and Speed	*IPS* Chapter 3*** — Characteristic Properties
	IPS Chapter 4 — Solubility	*FM&E* Chapter 5 — Waves	*IPS* Chapter 4 — Solubility
	IPS Chapter 5 — The Separation of Mixtures	*FM&E* Chapter 6 — Heating and Cooling	*IPS* Chapter 5 — Separation of Mixtures
	IPS Chapter 6 — Compounds and Elements	*FM&E* Chapter 7 — Potential Energy and Kinetic Energy	*IPS* Chapter 6 — Compounds and Elements
			IPS Chapter 7 — Radioactivity
			IPS Chapter 8 — The Atomic Model of Matter

			IPS Chapter 9 — Sizes and Masses of Molecules and Atoms
			IPS Chapter 10 — Electric Charge
			IPS Chapter 11 — Atoms and Electric Charge
			IPS Chapter 12 — Cells and Charge Carriers

* Omit Section 1.3 — Reading Scales.

** Omit Section 2.2 —Histograms, and Section 2.3 — Using a Computer to Draw Histograms.

*** Omit Section 3.3 —Graphing, Section 3.6 — **Experiment**: Mass and Volume, and Section 3.7 — Density.

**** Omit Section 2.2 — Mass, Volume, and Density.

Generic Equipment

Item	No.	Ch. 1	Ch. 2	Ch. 3	Ch. 4	Ch. 5	Ch. 6	Ch. 7
Balance, electronic or triple-beam	2						X	X
Beaker, 100 mL	12		X					
Beaker, graduated, 250 mL	12	X					X	
Blocks, wood for clapping	2					X		
Clamp, C 4-in.	12							X
Clamp, small pegboard	24		X					
Clamp, large pegboard	24		X					
Computer or graphing calculator	1				X	X		X
Computer interface	1				X			X
Cylinder, graduated, 10 mL	12		X					
Cylinder, graduated, 50 mL	12						X	
Eyedropper	12		X					
Goggles, safety	24	X					X	
Measuring tape, 50 m	1					X		
Meter stick	12		X		X	X	X	X
Metric ruler	12	X	X	X				
Motion detector	1				X			X
Pegboard	12		X					
Razor blade, single-edged, or scissors	12						X	
Scale, spring, 0–5 N	12	X						
Scale, spring, 0–10 N	12	X		X				
Softball	1							X
Spring, coil ("Slinky")	4					X		
Stopwatch	12				X	X		
Test tube, 25 mm x 150 mm, heat-res.	12						X	
Thermometer, –10˚C to 110˚C	12						X	
Washers, O.D. 4.5 cm, 31 g (approx.)	12						X	

FM&E Equipment

Item	No.	Ch. 1	Ch. 2	Ch. 3	Ch. 4	Ch. 5	Ch. 6	Ch. 7
Air puck kit	12			X				
Buoyancy set	12		X					
Cylinder set	12		X					
Force kit	12			X				
Friction block	12	X						
Friction block, large	1	X						
Gravitational-potential-energy kit	12							X
Kinetic-energy wheel and accessories	1							X
Magnetic-force apparatus	12	X						
Motion detector protector	1				X			X
Syringe kit	12		X					
Thermomter, high-resolution	12						X	X
Water-pressure tube set	1							

Supplies and Consumables

Item	No.	Ch. 1	Ch. 2	Ch. 3	Ch. 4	Ch. 5	Ch. 6	Ch. 7
Bags, small plastic								X
Cleaning solution (for table)	1	X						
Coffee filters, 6- to 8-cup size	12				X			
Coffee stirrers, hollow, package	1			X				
Conducting paste, container	1							X
Container, 1 gal plastic	12							X
Container, 1/2 gal plastic	12	X						
Cups, styrofoam, 8.5 oz	36						X	
Food coloring, red	1		X					
Ice cubes							X	X
Markers, transparency, package	1			X				
Masking tape, roll	1	X			X	X		
Oil, candle and lamp, bottle	1		X					
Paper, butcher's	12			X				
Paper, graph	24							
Paper towels, roll		X	X				X	X
Soapy water			X					
Straws, wide drinking, package	1			X				
String, roll	1						X	

Chapter 1
Forces

GENERAL COMMENTS

The balance between depth and breadth that is characteristic of this program manifests itself in every chapter, including this one. We introduce only four forces: The force of gravity near the surface of the earth, the elastic force of a spring, the magnetic force of a magnet, and the force of sliding friction. Furthermore, we discuss these forces only at or near equilibrium.

The experiments and reading sections are intended to provide the conceptual framework. By doing the problems at the end of the sections and the chapter, students get the practice needed to acquire the skills of problem solving.

SUGGESTED SCHEDULE

Sections 1–2: one experiment		2	periods
Sections 3-4: one experiment		3	periods
Section 5: one experiment		2	periods
Sections 6–7		2	periods
Chapter Test No. 1		2	periods
	TOTAL	11	periods

1.1 Introduction

The text begins with an experience common to all students. By use of student-performed experiments and readings that utilize experimental data and results, you can build the foundation for those concepts students are to learn.

This introductory section uses students' experiences with pushes and pulls to develop an operational definition of force. Two ways are introduced to tell whether a force is acting on an object. First, if an object at rest begins to move, there must be a force acting on it. Second, if we apply a force to an object and it does not move, then there must be another force (of equal strength and in the opposite direction) canceling our force.

Keep your discussion of this section simple and focused on these two postulates. There is no need to consider the effects of forces on moving objects. This situation will be investigated in Chapter 3.

1.2 Experiment: Weight and the Spring Scale

This experiment provides the basis for the use of the newton as the standard unit for force. You will need to lead your students through the procedure for reading the particular model of spring scale you have available. Before performing the experiment, limit this discussion to whether the force is read at the top of the "force indicator," at its center, or at its base. After students have completed the experiment, you can get into a more detailed discussion of the divisions on the newton scale, and how to estimate fractions of the smallest division.

Before students begin to collect data, you will need to assign an amount of water to be used by each lab group as their weight increment. The purpose of giving different stations different amounts of water is to emphasize the need for a standard unit of force. However, it is best to keep things simple. You may assign half the class to use increments of 150 cm^3 of water while the other half uses increments of 200 cm^3. These amounts can be measured easily with a 250-mL graduated beaker. To maintain a margin of safety regarding the 10-newton spring scales, no group should add more than a total of 750 cm^3 of water to the milk bottle. Also, if the spring scale's hook does not fit around the bottle's handle as shown in Fig. 1.2, you may need to attach wire or string to the handle to hold it securely to the hook.

If access to water is a problem, you may want to have additional plastic bottles or 500-mL beakers available to reduce the number of trips to a sink that each lab group must make for additional water.

The object used for the second part of this experiment (following the calibration with water) can be anything whose weight falls within the range of the 10-newton spring scale. This may include wooden blocks, fishing weights, small toy cars, or any other items of sufficient weight and interest to students, *provided all the objects used have the same weight.*

Students should try to estimate the weights of the objects before actually measuring them with the spring scale. This will foster a better "feel" for the weights and the scale we are using.

Differences in spring scales, inaccuracies in beaker graduations, and the different abilities of students to accurately mark their tapes lead to variations in the spacing of the marks as shown in the Sample Data. Typical variations can be seen in the Sample Data table. It may be necessary for each lab partner to take readings and then average the results to justify the conclusion that the spring scale stretches by equal amounts for equal weight increments.

Histograms will often be used to compare class data in this course. On the board or on an overhead, have lab groups contribute to class histograms showing the weights of each of the objects they measured in their arbitrary units. Since each histogram will show two distinct weight groupings for the same object — one for the groups who used increments of 150 cm^3 of water and one for those who used 200 cm^3 — the need for a standard unit of measurement will be dramatically demonstrated.

The Experiment

The data from Groups 1 and 2 were obtained with increments of 150 cm^3 of water while the data from Group 3 were obtained with increments of 200 cm^3.

One may see from Figure I that when the weight, to the nearest half unit, of the same object was determined by use of both these scales, two peaks occur on the histogram. Clearly the object's weight was measured by use of two different scales, and the need for a single scale is established.

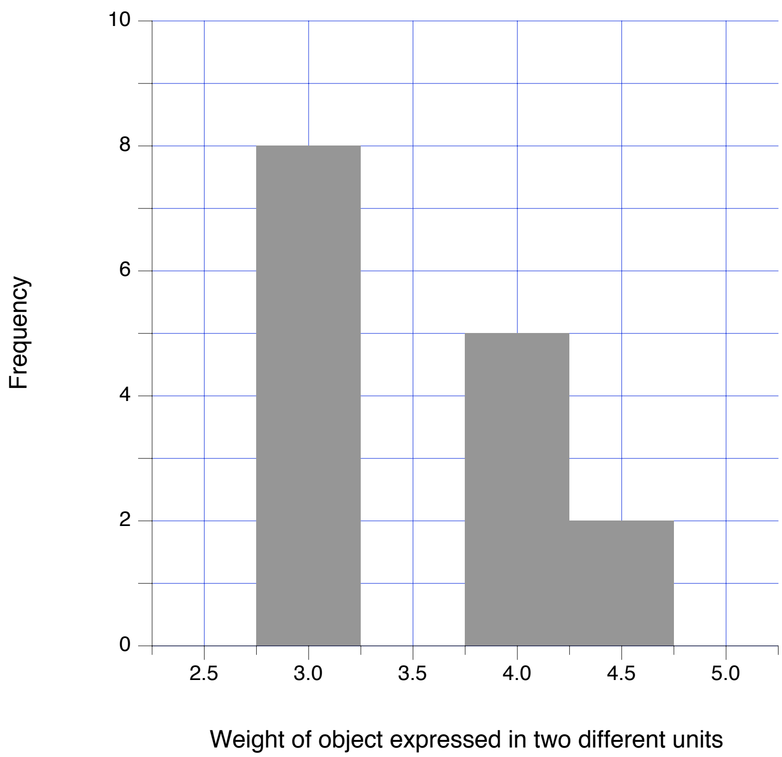

Figure I

Sample Data

Total amount of water added (units)	Distance between marks (mm)		Distance between marks (mm)
	Group 1	Group 2	Group 3
0	0	0	0
1	8.5	9.5	12.3
2	9.6	8.3	11.5
3	8.0	9.2	11.7
4	9.5	8.0	
5	8.9	9.1	

Answers to Questions

- Individual lab group measurements of the distances between the marks may differ. However, if each lab partner repeats the procedure and the measurements for each increment are averaged, the distances between each pair of consecutive marks will be seen to be the same.
- Because the distances between marks are the same, the spring scale must stretch by equal amounts for equal weight increments.
- The value of the division is a new unit of force that is half of what it was before. Depending on the weight increment used in the experiment, this unit will represent the weight of either 75 cm^3 or 100 cm^3 of water.
- Different lab groups report different results, but all of the results fall into two distinct groups depending on the unit of weight that was used.

Apparatus and Materials

Half-gallon plastic milk or juice bottle	Graduated beaker (250 mL)
Spring scale (0 – 10 N)	Masking tape
Second plastic bottle (optional)	

1.3 Hooke's Law: Proportionality

There are two important ideas to teach in this section. First, a graph of two quantities that are proportional appears as points lying on a straight line passing through the origin (0,0). Second, the analysis of experimental data for stretch and weight that shows the two to be proportional within a limited range. This generalization is known as Hooke's Law.

Students and classes vary in their experience and proficiency with graphing data. You may need to spend more or less time on this section based on the abilities of your students. Use the material in the Appendices 1 and 2 to help you. Emphasize that the ratio of stretch-to-weight is the same regardless of the two points along the graph's straight line used to calculate the ratio's value. Hence, knowing this ratio enables one to calculate the stretch caused by any weight or the weight producing any stretch for the data displayed on the axes of the graph.

1.4 The Magnetic Force

Students learned in Experiment 1.2, Weight and the Spring Scale, that a spring on a spring scale stretches equal distances for equal increases in weight. The proportional relationship, called Hooke's Law, between distance stretched and weight on a spring was introduced in Section 1.3.

The purpose of Experiment 1.4 is to establish the relationship between the force and distance of separation between two magnets. The magnetic force changes dramatically as the distance between two magnets is changed.

The Experiment

Strong neodymium magnets are used in this experiment. Be sure to discuss the cautionary statement with your students in order to avoid damage to various devices that might be in the classroom. Also, to avoid possible damage to the equipment, remind students to slide the magnets apart if they ever become placed together without any spacers between them.

Students may obtain a magnet in a block and one on a string that repel each other. These magnets are obviously not paired, and you can be sure that another student has the same problem. These students need to switch their magnets tied to the string. This problem is avoided if the magnets are stored and distributed so that the one on the string sits firmly atop the two permanent separators and bound to the magnet embedded in the wood base. Storing magnets this way does not harm them.

Be sure to take time to discuss with students what data should be recorded in a data table. Deciding on the quantities to measure is not an easy task for many students. A sample data and calculation table is shown in the Sample Data section below.

The technique introduced for measuring the thickness of the spacers is useful to reduce the measurement error inherent in making small measurements.

Zeroing the spring scale compensates for two effects—the weight of the upper magnet assembly pulling downward and the upward attraction of the magnet to the metal hook of the spring scale. To minimize this latter effect, the string used to suspend the top magnet from the spring scale should be at least 12–15 centimeters long.

It may be necessary for students to repeat each reading several times in order to measure the forces accurately. Fortunately, this is not difficult since the magnets will pull themselves back into the proper alignment each time they are brought near each other. However, to get the best possible results, students should pull straight upward with the spring scale rather than at an angle different from vertical.

Caution students against looking down on the apparatus from above as they pull on the magnet, since the magnets may spring apart very quickly. Most of the time, the top magnet will spring up and attach itself to the metal hook of the spring scale, but on rare occasions it may miss the hook. Thus the need for safety glasses.

Sample Data

Number of spacers	Force (newtons)	Calculated separation distance (centimeters)
10	0.25	1.22
9	0.35	1.09
8	0.52	0.97
7	0.60	0.85
6	0.78	0.73
5	1.08	0.61
4	1.55	0.49
3	2.32	0.36
2	3.75	0.24
2	3.70	0.24
3	2.30	0.36
4	1.52	0.49
5	1.10	0.61
6	0.78	0.73
7	0.55	0.85
8	0.52	0.97
9	0.32	1.09
10	0.25	1.22

The readings at each separation are averaged to construct the force-versus-separation graph (Figure II).

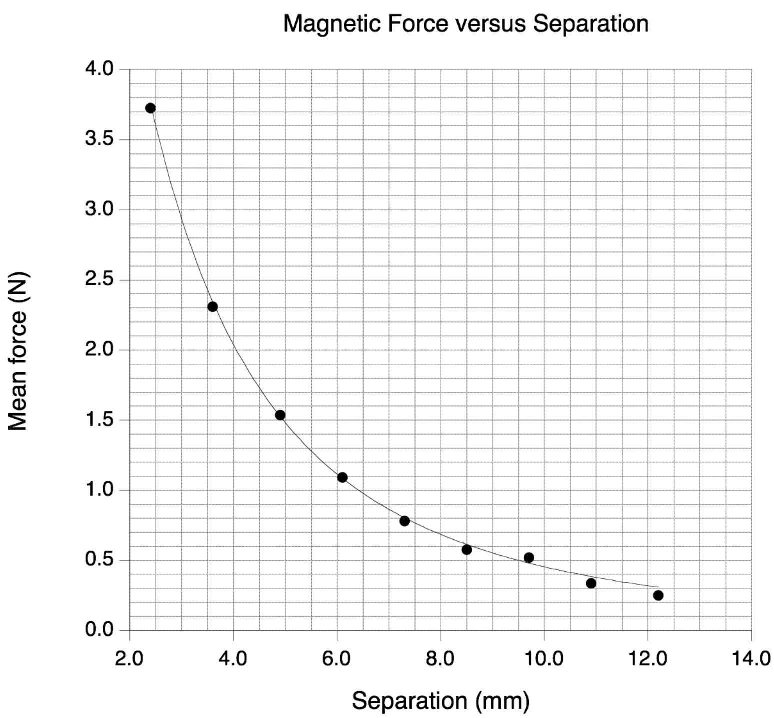

Figure II

There is no need to provide the class with a mathematical formula for the observed curve. For your own understanding, the following information may be of interest. If the length of each magnet l were much greater than the separation r between the magnets ($l>>r$), then we would expect the behavior of the force to approach something like an inverse-square relationship ($1/r^2$) with the separation. If the length is much less than the separation distance ($l<<r$), the force dependence on the separation will approach an inverse fourth-power ($1/r^4$) relationship. Thus it is not surprising that in our experiment, where we are operating between these two extremes, the best-fit curve shows an exponent of about 3 rather than 2 or 4. What is important in this experiment is for your students to realize that some forces are not proportional to distance, but become very large at small distances and very small at large distances.

Answers to Questions

- Measuring the height of the stack of spacers is more accurate than measuring the thickness of just one spacer. The height of the stack can then be divided by the number of spacers in the stack to obtain the thickness of one spacer.
- The thickness of one spacer is (1.22 cm)/10 = 0.122 cm.
- Force, measured in newtons, is on the vertical axis. The separation of the magnets, measured in millimeters, is located on the horizontal axis. The curve falls steeply at first on the left side of the graph, tending to level off to the right.
- The magnetic force tends to drop much less as the separation between magnets becomes greater and greater and would appear to become nearly zero if the separation were exceedingly large. (Students may express this general idea in many different and acceptable ways.)

Apparatus and Materials

Magnetic force apparatus	Spring scale (0–5 N)
Ruler (metric)	

1.5 Experiment: Sliding Friction

This is likely to be your students' first exposure to a scientific investigation of friction. This investigation is designed to teach students that (1) the area of the surfaces in contact is *not* a factor but (2) the kind of surfaces in contact *do* affect the size of the frictional force. Section 1.6 will extend the investigation to the effect of weight on the frictional force.

Students should all use the same kind of surface if they are to compare their data. Lab tabletops must be cleaned thoroughly. Two ways of doing this are possible. If your lab tables have a uniform surface, students may use a mild cleaning solution to scrub the paths over which the friction blocks will slide and dry them to clear away any residue. A second option for providing a clean, uniform path is to cover the lab tables with sheets of melamine, a plastic material. A small bottle of rubbing alcohol and a rag should be available to clean both the melamine surface and the covered surfaces of the wood blocks.

The Experiment

Friction within the spring scale can easily interfere with students' results in this experiment. Explain to students that they must be careful not to twist the spring scale as they pull the friction block.

The technique will also take practice to master, so be sure to allow sufficient time. Students need to pull with enough force to overcome static friction, but once the block is moving, they must decrease the pull until they find the smallest force that will keep the block moving.

The force measurements require very careful observation. The technique involves increasing the pulling force by 0.1 N increments until static friction is overcome and the block begins to move, and then backing off by 0.05 N increments until the smallest force that will keep the block moving, *no matter how slowly*, is determined. This is most easily done with one student carefully concentrating on the spring scale reading while a second student watches to see whether the block continues to move.

Because the forces involved are small, be sure to compile class results into four histograms so your students can better compare the data.

Sample Data

Values will vary depending on the surface of the table. The dependence of the frictional force on the type of surface and not its area is shown by the two peaks on the histogram in Figure III

The force required to barely move the block on a tabletop

	Force—(N) covered	Force (N)—uncovered
Wide surface	0.9	0.3
Narrow surface	1.0	0.3

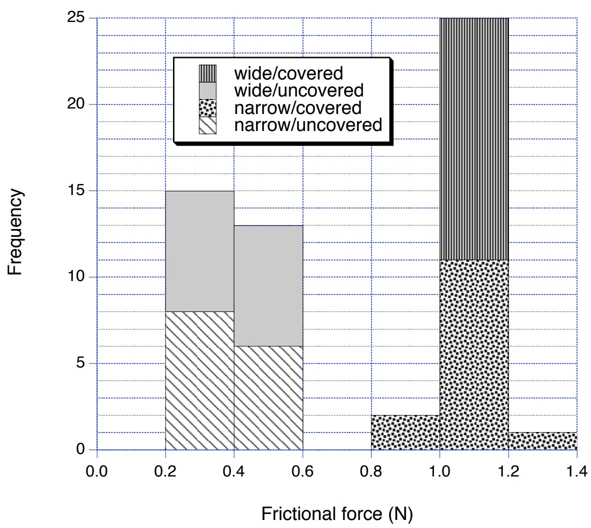

Figure III

Answers to Questions

- Answers may vary slightly depending on the equipment. A typical value for the covered surfaces is 0.9 N, as shown in the Sample Data above.

- If the hook connecting the spring scale and block does not touch the table, the frictional force between the spring scale and the table only affects the force that the experimenter exerts to move the entire assembly. It does not affect the force exerted by the spring to move the block, which is recorded on the newton scale.
- The smallest force is now smaller than before. The Sample Data shows that a typical value is 0.3 N for the uncovered surfaces.
- Because different values of force are required to keep the block moving when different surfaces are in contact, we may conclude that the frictional force does depend on the types of surfaces that are in contact.
- Because the same force is required to move the block regardless of the area of contact between the block and table, we may conclude that the frictional force does not depend on the area of contact for the range of areas used in this experiment.

Apparatus and Materials

Friction block — Spring scale (0–5 N)

1.6 Friction and Weight

This reading section requires students to interpret data in order to learn how the frictional force between an object and a surface is related to the weight of the object.

You may want to have some students do this experiment as a project. If so, you will need six to eight weights, each of approximately 0.5 newtons. As an alternative, you can use a paper cup to which 0.5 N of sand (a mass of approximately 50 g) at a time may be added. Whatever masses are used, they must be evenly distributed on top of the block to avoid creating a torque as the block is pulled.

1.7 Newton's Third Law

Newton's third law is often misunderstood. A common misunderstanding is that the force that object A exerts on object B cancels the force object B exerts on object A. Forces acting on different objects do not cancel one another even if they are equal in magnitude and opposite in direction. Keep in mind that if two bodies remain at rest while they exert a force on each other, additional forces must act on those bodies to keep them at rest.

Read this section in class with special attention to Figures 1.10 and 1.11. There is nothing to be gained by referring to "action" and "reaction" in talking about Newton's third law. It may suggest to students that one force causes the other, which is not true; the forces are symmetric.

Newton's first law will be discussed in Section 3.6.

Answers to Problems

The table below classifies problems according to their estimated level of difficulty and the sections they relate to. In addition to the questions listed in the last row (RAEs), there may be others that you will want to extend into lab or home experiments.

SECTION	EASY	MEDIUM	HARD
1	1		
2	3	2, 4, 5	
3	6	8	7
4	9		
5	10	11	
6	14	12	13, 15
7			16, 17
RAEs		19	18, 20

1. Does a table exert a force on a cup that rests on it? Explain.

We know that if the table were not there, the cup would fall. So there must be a downward force on the cup. But while the cup is on the table, it does not move. Knowing this, we can say that there must be another force canceling the downward force. The table must be pushing upward on the cup.

2. The spring that you will use in the next section is different from the one you used in this section.

a. Pull gently on the two springs. Describe the difference between the springs.

b. Suppose you hang identical objects on each spring scale. When the objects are at rest, which spring will stretch more? Explain.

c. Does one spring exert a greater force on the object than the other spring? Explain.

a. One spring requires a weaker pull to stretch it apart.

b. When identical objects hang from each spring so that they are pulled apart with the same force, the weaker spring stretches apart the most.

c. No, each spring exerts the same force on the object hanging from it because the two objects are identical.