3.1 Gravitational Force on Earth's Surface

This section presents Earth's gravitational field, compares mass and weight in a specific context, and explores how "weightlessness" and "microgravity" relate to constant free fall.

Achievement Chart Categories	Assessment Opportunities/Specific Expectation Addressed	Assessment Tools
Knowledge/Understanding	Practice Questions Understanding Concepts, q. 1–14 FM1.05 Section 3.1 Questions Understanding Concepts, q. 1–9 FM1.05	Rubric 1: Knowledge/Understanding
Inquiry	Section 3.1 Questions Applying Inquiry Skills, q. 10 FM1.05	Rubric 2: Inquiry Skills
Communication	Section 3.1 Questions Making Connections, q. 11 FM1.05	Rubric 3: Communication
Making Connections	Section 3.1 Questions Making Connections, q. 12 FM1.05	Rubric 4: Making Connections

Expectations Addressed

Overall Expectations—FMV.01
Overall Skills Expectations—SIS.06, SIS.08, SIS.09, SIS.011
Specific Expectations:

- FM1.05 analyze and describe the gravitational force acting on an object near, and at a distance from, the surface of the Earth

BACKGROUND INFORMATION

This section is introduced using the context of overcoming gravity in sports records, which are slightly easier to break at locations near the equator and at high altitudes. For any athlete, a personal record may be exceeded by less than half a percentage point, which may be enough to break a record.

Force fields are rather abstract and difficult for some students to understand, and Earth's gravitational field is no exception. Every object with mass has a gravitational field around it, but the strength of the field (in newtons per kilogram) does not have a noticeable effect on other masses unless the object has a very large mass (such as Earth, the Moon, the Sun, etc.). The gravitational field is numerically equivalent to the acceleration due to gravity, as students are asked to show in Practice Question 1, page 85.

The differences between mass and weight have been taught in science and physics classes for generations, and the results are starting to be observed. For example, some information charts ask for a person's height and mass, and TV shows involving forensic science use "mass" in the scientific sense.

The gravitational field strength at the Earth's surface varies slightly depending on the distance from Earth's centre. Thus, at higher altitudes, the field strength is slightly lower. Also, because Earth is bulged outward slightly at the equator, the field strength there is less than at the poles. Local variations in the gravitational field strength also occur; these are caused by various factors, such as mountain and valley shapes, and mineral deposits.

Since weight is the force of gravity acting on an object, one would expect "weightless" to mean zero force of gravity acting on the object. This is often confused with constant free fall, in which there is no upward force on the object, giving the sensation of weightlessness. The text explains why weightlessness and microgravity are misleading terms for constant free fall. An alternative name for this phenomenon is "apparent weightlessness," a term used in many advanced physics texts.

The explanation of why astronauts experience apparent weightlessness in their training aircraft (see Figure 8, page 88) involves an analysis of centripetal motion, a topic explained in detail in grade 12 physics. On the upward part of the flight, the pilot changes the controls, causing the plane to no longer exert much upward force (the normal force) on the occupants. At the top of the flight, the normal force drops to zero, and the sensation of weightlessness is most obvious there. Refer to the Teaching Suggestions on demonstrating this situation in class.

ADDRESSING ALTERNATIVE CONCEPTIONS

In everyday usage, mass and weight are often considered the same. To emphasize the differences between the two quantities, have the students compare their mass and weight on Earth with their mass and weight on the Moon, where the gravitational field strength is 1.6 N/kg. Also, in Practice Question 6, page 86, ask the students to add another column indicating the "type of quantity" for each (mass is scalar; weight is vector).

A major misconception relates to the words weightlessness and microgravity. The media and even some NASA scientists and astronauts use these terms loosely and incorrectly. To show students that the force of gravity on the International Space Station is about 90% of what it is on Earth's surface (as stated on page 88), have them look ahead to page 92 and apply the law of universal gravitation to calculate the force of gravitational attraction on a 1.0 kg mass at a height of 450 km above Earth's surface (where the Space Station orbits). Note that data for Earth are found in Appendix C on page 577.

Related Background Resources

The following products are available from Boreal Laboratories (www.boreal.com):

- apparent weightlessness demonstration, #46327-00, about $100
- *Reduced Gravity* (video), #73994-00, about $30

The following equipment is available from Northwest Scientific Supply (www.nwscience.com) (it must be used with a rotator):

- centrifugal hoops demonstration apparatus, #24-5027, $60

Nelson Web site:
www.science.nelson.com
for specific Web links

PLANNING

Suggested Time

Narrative/Practice Questions—35 to 45 minutes
Section Questions—20 to 30 minutes

Core Instructional Resources

- Solutions Manual
- Colour Transparencies
- Reference to the Appendixes: Appendix C has data for Earth.

Supplemental Resources

- Lab and Study Blackline Masters

TEACHING SUGGESTIONS

- Have a plumb bob and a level available to show simple applications of the force of gravity on (or near) the Earth's surface. If a commercial plumb bob is not available, you can make one using a rubber stopper attached to a string.
- To help visualize force fields, remind the students that they have studied fields other than gravitational force fields before. For example, magnetic fields are observed using iron filings (see page 473) and electric fields are observed in demonstrations of static electricity (page 423).
- Relate the Earth's gravitational field strength to the observations students made in the Try This Activity that introduces Chapter 2 (page 53), where the data yielded a value of 9.8 N/kg.
- To explain why Earth is slightly flatter at the poles than at the equator, discuss how Earth's rotation on its axis has caused the bulging outward at the equator, just like the rotation of a washing machine causes the clothes to tend to move outward. A device called "centrifugal hoops," consisting of flexible metal strips connected like a large eggbeater, can be rotated at various frequencies to illustrate this principle.
- To illustrate why the normal force acting on occupants at the top of a parabolic path drops to zero, twirl a small rubber stopper attached securely to a string in a vertical circle. Start with a fairly high (but safe!) speed, then gradually slow the speed down until the stopper barely makes it across the top of the arc. At this stage, the tension in the string drops to zero, and just before and after passing the top of the arc, the tension is nearly zero. When the tension in the string is zero, the only force acting on the object is gravity. Similarly, when the normal force acting on the plane's occupants is zero, the only force acting on the occupants is gravity.