Introductory Physics, High School

Learning Standards for a Full First-Year Course

I. Content Standards

1. Motion and Forces
Central Concept: Newton's laws of motion and gravitation describe and predict the motion of most objects.

1.1 Compare and contrast vector quantities (e.g., displacement, velocity, acceleration force, linear momentum) and scalar quantities (e.g., distance, speed, energy, mass, work).
1.2 Distinguish between displacement, distance, velocity, speed, and acceleration. Solve problems involving displacement, distance, velocity, speed, and constant acceleration.
1.3 Create and interpret graphs of 1-dimensional motion, such as position vs. time, distance vs. time, speed vs. time, velocity vs. time, and acceleration vs. time where acceleration is constant.
1.4 Interpret and apply Newton's three laws of motion.
1.5 Use a free-body force diagram to show forces acting on a system consisting of a pair of interacting objects. For a diagram with only co-linear forces, determine the net force acting on a system and between the objects.
1.6 Distinguish qualitatively between static and kinetic friction, and describe their effects on the motion of objects.
1.7 Describe Newton's law of universal gravitation in terms of the attraction between two objects, their masses, and the distance between them.
1.8 Describe conceptually the forces involved in circular motion.

2. Conservation of Energy and Momentum
Central Concept: The laws of conservation of energy and momentum provide alternate approaches to predict and describe the movement of objects.

2.1 Interpret and provide examples that illustrate the law of conservation of energy.
2.2 Interpret and provide examples of how energy can be converted from gravitational potential energy to kinetic energy and vice versa.
2.3 Describe both qualitatively and quantitatively how work can be expressed as a change in mechanical energy.
2.4 Describe both qualitatively and quantitatively the concept of power as work done per unit time.
2.5 Provide and interpret examples showing that linear momentum is the product of mass and velocity, and is always conserved (law of conservation of momentum). Calculate the momentum of an object.

3. Heat and Heat Transfer
Central Concept: Heat is energy that is transferred by the processes of convection, conduction, and radiation between objects or regions that are at different temperatures.

3.1 Explain how heat energy is transferred by convection, conduction, and radiation.
3.2 Explain how heat energy will move from a higher temperature to a lower temperature until equilibrium is reached.
3.3 Describe the relationship between average molecular kinetic energy and temperature. Recognize that energy is absorbed when a substance changes from a solid to a liquid to a gas, and that energy is released when a substance changes from a gas to a liquid to a solid. Explain the relationships among evaporation, condensation, cooling, and warming.

3. Heat and Heat Transfer (cont.)

3.4 Explain the relationships among temperature changes in a substance, the amount of heat transferred, the amount (mass) of the substance, and the specific heat of the substance.

4. Waves

Central Concept: Waves carry energy from place to place without the transfer of matter.

4.1 Describe the measurable properties of waves (velocity, frequency, wavelength, amplitude, period) and explain the relationships among them. Recognize examples of simple harmonic motion.
4.2 Distinguish between mechanical and electromagnetic waves.
4.3 Distinguish between the two types of mechanical waves, transverse and longitudinal.
4.4 Describe qualitatively the basic principles of reflection and refraction of waves.
4.5 Recognize that mechanical waves generally move faster through a solid than through a liquid and faster through a liquid than through a gas.
4.6 Describe the apparent change in frequency of waves due to the motion of a source or a receiver (the Doppler effect).

5. Electromagnetism

Central Concept: Stationary and moving charged particles result in the phenomena known as electricity and magnetism.

5.1 Recognize that an electric charge tends to be static on insulators and can move on and in conductors. Explain that energy can produce a separation of charges.
5.2 Develop qualitative and quantitative understandings of current, voltage, resistance, and the connections among them (Ohm's law).
5.3 Analyze simple arrangements of electrical components in both series and parallel circuits. Recognize symbols and understand the functions of common circuit elements (battery, connecting wire, switch, fuse, resistance) in a schematic diagram.
5.4 Describe conceptually the attractive or repulsive forces between objects relative to their charges and the distance between them (Coulomb's law).
5.5 Explain how electric current is a flow of charge caused by a potential difference (voltage), and how power is equal to current multiplied by voltage.
5.6 Recognize that moving electric charges produce magnetic forces and moving magnets produce electric forces. Recognize that the interplay of electric and magnetic forces is the basis for electric motors, generators, and other technologies.

6. Electromagnetic Radiation

Central Concept: Oscillating electric or magnetic fields can generate electromagnetic waves over a wide spectrum.

6.1 Recognize that electromagnetic waves are transverse waves and travel at the speed of light through a vacuum.
6.2 Describe the electromagnetic spectrum in terms of frequency and wavelength, and identify the locations of radio waves, microwaves, infrared radiation, visible light (red, orange, yellow, green, blue, indigo, and violet), ultraviolet rays, x-rays, and gamma rays on the spectrum.

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II. Scientific Inquiry Skills Standards

Scientific literacy can be achieved as students inquire about the physical world. The curriculum should include substantial hands-on laboratory and field experiences, as appropriate, for students to develop and use scientific skills in introductory physics, along with the inquiry skills listed below.

SIS1. Make observations, raise questions, and formulate hypotheses.

- Observe the world from a scientific perspective.
- Pose questions and form hypotheses based on personal observations, scientific articles, experiments, and knowledge.
- Read, interpret, and examine the credibility and validity of scientific claims in different sources of information, such as scientific articles, advertisements, or media stories.

SIS2. Design and conduct scientific investigations.

- Articulate and explain the major concepts being investigated and the purpose of an investigation.
- Select required materials, equipment, and conditions for conducting an experiment.
- Identify independent and dependent variables.
- Write procedures that are clear and replicable.
- Employ appropriate methods for accurately and consistently
    - making observations
    - making and recording measurements at appropriate levels of precision
    - collecting data or evidence in an organized way
- Properly use instruments, equipment, and materials (e.g., scales, probeware, meter sticks, microscopes, computers) including set-up, calibration (if required), technique, maintenance, and storage.
- Follow safety guidelines.

SIS3. Analyze and interpret results of scientific investigations.

- Present relationships between and among variables in appropriate forms.
    - Represent data and relationships between and among variables in charts and graphs.
    - Use appropriate technology (e.g., graphing software) and other tools.
- Use mathematical operations to analyze and interpret data results.
- Assess the reliability of data and identify reasons for inconsistent results, such as sources of error or uncontrolled conditions.
- Use results of an experiment to develop a conclusion to an investigation that addresses the initial questions and supports or refutes the stated hypothesis.
- State questions raised by an experiment that may require further investigation.

SIS4. Communicate and apply the results of scientific investigations.

- Develop descriptions of and explanations for scientific concepts that were a focus of one or more investigations.
- Review information, explain statistical analysis, and summarize data collected and analyzed as the result of an investigation.
- Explain diagrams and charts that represent relationships of variables.
- Construct a reasoned argument and respond appropriately to critical comments and questions.
- Use language and vocabulary appropriately, speak clearly and logically, and use appropriate technology (e.g., presentation software) and other tools to present findings.
- Use and refine scientific models that simulate physical processes or phenomena.

III. Mathematical Skills

Students are expected to know the content of the *Massachusetts Mathematics Curriculum Framework,* through grade 8. Below are some specific skills from the *Mathematics Framework* that students in this course should have the opportunity to apply:

✓ Construct and use tables and graphs to interpret data sets.
✓ Solve simple algebraic expressions.
✓ Perform basic statistical procedures to analyze the center and spread of data.
✓ Measure with accuracy and precision (e.g., length, volume, mass, temperature, time)
✓ Convert within a unit (e.g., centimeters to meters).
✓ Use common prefixes such as *milli-, centi-,* and *kilo*-.
✓ Use scientific notation, where appropriate.
✓ Use ratio and proportion to solve problems.

The following skills are not detailed in the *Mathematics Framework*, but are necessary for a solid understanding in this course:

✓ Determine the correct number of significant figures.
✓ Determine percent error from experimental and accepted values.
✓ Use appropriate metric/standard international (SI) units of measurement for mass (kg); length (m); time (s); force (N); speed (m/s); acceleration (m/s^2); frequency (Hz); work and energy (J); power (W); momentum (kg•m/s); electric current (A); electric potential difference/voltage (V); and electric resistance (Ω).
✓ Use the Celsius and Kelvin scales.

Accelerating Cars

Introductory Physics, High School

Acceleration is a concept Ms. Luke chooses to teach students early in her introductory physics class. Many students are aware that acceleration means that an object moves faster, but Ms. Luke has found that students often have difficulty articulating how to measure acceleration and graphically relating acceleration to changes in speed. She decides to teach these concepts by using something with which all her students are familiar; cars.

In an opening dialog, Ms. Luke and her students together define speed and velocity, and how they are calculated. They then move on to the more challenging concept of acceleration, including deceleration, no acceleration, and constant acceleration. Ms. Luke asks, "How can you tell something is accelerating?" One student quickly mentions using a speedometer. Another student mentions "that thing that measures how fast you walk," which Ms. Luke identifies as a pedometer. "How can you use a speedometer, for example, to measure acceleration?" she asks. "Or, if you didn't have an speedometer or pedometer, how would you know that the object is accelerating?"

After listening to student responses, without accepting or dismissing any of them, Ms. Luke proposes that the class go outside to observe whether cars that drive by the front of the school build up speed, slow down, or maintain a constant speed over a given distance. With the data students collect, they will relate what they see and hear to a graph of each car's speed and an analysis of its acceleration.

The students are organized into small groups. Each group stands on the sidewalk along a stretch of road identified by Ms. Luke, separated from the next group by twenty meters. Ms. Luke has already marked off 20-meter increments. She has chosen to use a strip of road that begins at the stop sign in front of the school and includes the downward sloping hill beyond. Here she knows her students will have a good opportunity to observe different rates of speed and acceleration. The students are equipped with stopwatches and their lab notebooks. Each group knows to measure and record the time it takes a car to travel from the stop sign to their position. They are also instructed to record observations of each car while it is in their assigned zone, including the sound of its engine and whether the brake lights are on. The groups record data for five cars identified by Ms. Luke before going back into class to work through their calculations, graph their data, and answer the key questions of the activity.

Upon reentering the classroom, the students record their data on the board. Ms. Luke asks one student to demonstrate how to calculate the speed of one car, within that student's assigned zone, using the data from the student's group plus the data of the group positioned just uphill of them. Each group then records the speed of each car in their zone on a class chart for everyone to see. Ms. Luke also asks students to relate these calculations to their observations of the cars. Ms. Luke then asks her students to consider, "What does the graph of the speed of each car over the entire stretch of road look like?" She has each student make a position vs. time graph and a velocity vs. time graph for each car. Ms. Luke has the students annotate each graph with their observations of that car. From these graphs the class compares change in speed for the cars relative to each other.

Ms. Luke then asks the class to focus on the speed vs. time graph of the first car, which she projects for everyone to see. They notice that the points on the graph do not form a continuous straight line across the grid, but instead go up, straight across, and then down slightly in the last segment. "What does this mean?" she asks. "It means that the car sped up and slowed down," offers one student. "It means that the car accelerated from here to here," another student points out on the graph, "but then it stopped speeding up from here to here." She asks the students to confirm this against their observations of the car.

Ms. Luke then says to the class, "Determine if each car accelerated, decelerated, or showed no acceleration over any period of time. If a car did accelerate or decelerate at some time, did it keep doing so at the same rate?"

Finally, Ms. Luke instructs the students to circle and notate the places on each graph where that car possibly accelerated, decelerated, or showed no acceleration. To quantify the areas circled, she has the students calculate the acceleration from one zone to the next, pointing out that a negative result means that the car slowed down or decelerated, and a zero result means that the car maintained its speed. Ms. Luke also instructs her students to look for instances where the acceleration is the same for two or more adjacent places on the graph, and to label those instances as constant acceleration.

Assessment Strategies

- Students should pay particular attention to the construction and labeling of graphs. They should use units appropriately throughout their work.
- Students can write out a scenario that aligns with the changes in speeds on the graphs they have created themselves. Students should properly use the terms "speed," "velocity," "acceleration," "deceleration," "no acceleration," and "constant acceleration" in their scenarios.
- As a follow-up assignment, the students can create a data chart that includes distance, time, and speed of a fictitious vehicle. With this data, they create a speed vs. time graph. Their data must show acceleration, deceleration, no acceleration, and constant acceleration on their graph. They should also calculate acceleration.

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1.2 Distinguish between displacement, distance, velocity, speed, and acceleration. Solve problems involving displacement, distance, velocity, speed and constant acceleration.

1.3 Create and interpret graphs of 1-dimensional motion, such as position vs. time, distance vs. time, speed vs. time, velocity vs. time, and acceleration vs. time where acceleration is constant.

Scientific Inquiry Skills Standards that apply

High School

SIS2. Design and conduct scientific investigations.
- Employ appropriate methods for accurately and consistently
  - making observations
  - making and recording measurements at appropriate levels of precision
  - collecting data or evidence in an organized way

SIS3. Analyze and interpret results of scientific investigations.
- Use mathematical operations to analyze and interpret data results.

SIS4. Communicate and apply the results of scientific investigations.
- Explain diagrams and charts that represent relationships of variables.