Appendix: Sample Learning Sequences for Various Topics in Introductory Physics*

* These learning cycles are to be considered drafts. Even in this form, they serve as examples of the sort of work that teacher candidates can do in about 30-45 minutes.

Topic	Discovery Learning	Interactive Demonstration	Inquiry Lesson	Inquiry Lab
Simple Pendulum	Students develop an understanding of the concept of oscillatory motion. They characterize and conceptualize the motion and components by "playing" with one of varying pendulum configurations (varying mass, length, and amplitude). Students characterize the system and identify variables and parameters of pendulums in general such as bob mass, string length, amplitude, magnitude of gravitational force constant, and the period.	Students observe to determine qualitatively what effects, if any, changing system variables have on the period of a pendulum. Students search for principles. Actions are undertaken to see if changing pertinent variables affect the period of the pendulum (bob mass, string length, and initial angle) and develop a conceptual relationship between variables (e.g., changing mass has no affect on the period). Make data tables of mass vs. period, length vs. period, and amplitude vs. period.	Using stopwatches, meter sticks, and protractors, students conduct a controlled experiment (under fixed gravitational force constant "*g*") to collect data to determine the exact relationship between string length and period. That is, $P = k\sqrt{l}$. Help students see that the slope of the length vs. period graph can be related to the gravitational force constant, *g*. Using and dimensional analysis (see *Student Laboratory Handbook*), show that $P = 2\pi\sqrt{l/g}$.	Students use protractors and stopwatches to test different amplitudes to discover the accuracy of the small angle approximation in the relationship. Compare experimental values of period for various amplitudes with predicted values from constant angle formula and make a chart. Determine at what angle (amplitude) the predicted period diverge from the actual period by more than 5%.
	Hypothetical Inquiry: More advanced students might be invited to develop a theoretical relationship for the period of a pendulum using Newton's second law. That is, $-mg\sin\theta = m\ddot{x}$ from which is the standard relationship can be derived.			
Work & Power	**Discovery Learning:** Students develop an understanding of the concept of work (in the physical sense) by lifting objects of different mass different distances. Distinguish between physiological work and physical work. (Is it "work" to hold a non-moving object?) Students develop an understanding of the concept of power by running and walking up and down stairs. Ask, "Are rates of "exertion" the same? What term might we use to talk about energy expended over time?	**Interactive Demonstration:** Develop the mathematical definition of physical work, $W = Fd$. Have students determine the amount of work required to life an object straight up a given distance. Ask questions about simple machines. Do they provide something for nothing? E.g., free work? Develop the mathematical definition of power, $P = W/t$, here as well. Power is the rate at which energy is expended. Note work-energy theorem if appropriate.	**Inquiry Lesson**: Using spring scales, determine the amount of work required to move a cart up different inclined planets at constant speed. Determine the values of *F* and *d* to calculate work. Compare. Help students see that work is independent of path moving vertically in the earth's gravitational field from point d_i to point d_f. $W \neq f(path)$	**Inquiry Lab:** Determine the amount of work performed by a DC motor as it lifts a mass *m* distance *d* in a gravitational field with strength *g* and at a constant speed. Next, determine the power required to perform this work in time interval *t*. Compare experimental work ($W = mgd$) with theoretical work determined from *P* = *IV*. Introduce the concept of efficiency, *e*. Determine *e* for the motor. $e = \frac{P_{out}}{P_{in}} = \frac{W/t}{IV}$

Spring Laws	**Discovery Learning:** Students are given a variety of springs to examine with the teacher focusing student action with and attention to the following concepts: spring constant, applied force, restoring force, equilibrium position, displacement from equilibrium, compression, and extension.	**Interactive Demonstration:** The teacher demonstrates effects of attaching masses to a vertically suspended spring. Focus is on students developing an understanding of the relationship between force on a spring and its extension from equilibrium position. Misconceptions are addressed as appropriate.	**Inquiry Lesson**: The students, conducting a whole class lab under the guidance of the teacher, work out Hooke's law for springs ($F = -kx$). The apparatus from the interactive demonstration is used, but now with data collection and graphing to find the relationship between F and x.	**Inquiry Lab:** Students extend their study of Hooke's law by determining the effect of adding two springs with different spring constants (k) in series, and the effect of adding two identical springs in parallel. Determine the effective spring constant of two identical springs on a horizontal spring system with an oscillating mass.
	Hypothetical Inquiry: Using Hooke's Law, $\boldsymbol{F} = -k\boldsymbol{x}$, show that the equivalent spring constant for two springs in parallel is $k_{eq} = k_1 + k_2$ where k_1 and $k_2$are the spring constants of the springs. Using Hooke's Law, $\boldsymbol{F} = -k\boldsymbol{x}$, show that the equavalent spring constant for two springs in series is $\frac{1}{k_{eq}} = \frac{1}{k_1} + \frac{1}{k_2}$.			
Oscillating Springs	**Discovery Learning:** Students are provided with a suspended spring and masses and encouraged to examine the system. The teacher asks, "Is there a relationship between mass on the spring, how far it is displaced from equilibrium, and between how frequently is goes up and down? Develop the concepts of frequency, period, and amplitude.	**Interactive Demonstration:** The teacher pulls down on a weight attached to a vertically suspended spring and asks, "What happens when the amount of suspended mass is increased?" and "What happens with the same amount of mass but with different spring constants?" The teacher, working with student participation, conducts activities addressing misconceptions as appropriate.	**Inquiry Lesson**: The teacher helps the students to develop a mathematical model to rep-resent an oscillating horizontal system using dimensional analysis. That is, $f = c\sqrt{k/m}$. (For information about dimensional analysis, visit the Illinois State University Physics Department's *Student Lab Handbook*.)	**Inquiry Lab:** Students experimentally verify the model's relationship $f = c\sqrt{k/m}$ and find the constant of proportionality, $c = 1/2\pi$, through a controlled experiment where the mass is varied and the corresponding frequency measured. Students are given a horizontal spring attached to a car on a track and a set of masses to conduct the experiment.
Friction	**Discovery Learning:** Students push/pull different objects (e.g., ice cubes, kinematics cart/toy car, wooden blocks) and resulting motion is observed. The teacher asks, "Why do they move with different speeds? Why do they stop?" Introduce concept that friction is a resistive force that opposes motion.	**Interactive Demonstration:** The students' attention is focused on different surface types and how this relates to the angle at which they start sliding down a more and more inclined plane. The teacher asks, "Why do different objects start sliding down the incline at different angles? Does the nature of surface matter? How do various surfaces interact?"	**Inquiry Lesson**: Student conduct simple tests under guidance of teacher to determine which factors influence amount of friction an object encounters. They test these factors as a class to eliminate factors that have no bearing. Possible factors include the following: normal force, weight, rolling/sliding, surface type, speed, surface area, etc.	**Inquiry Lab:** Students conduct quantitative experiments to determine which factors actually influence friction. Materials are provided and students guided in the design of the experiment. Students will use kinematics carts and force sensors to collect measurements of the force applied on the cart. Students are helped to "discover" $F=\mu N$.
	Hypothetical inquiry: Factors identified, students design lab activity and request materials, combination of inquiry lesson and inquiry lab, more freedom to design own "problem" on topic of friction; sandpaper with different grids sizes might be a good resource for this type of learning.			

Circular Motion	**Discovery Learning:** Students work through a stations lab to seek similarities between systems that experience circular motion (i.e. paper bits on a rotating record, penny in a donation funnel, ball on a string, spinning globe, etc.). Concepts of period, frequency, and tangential velocity are worked out.	**Interactive Demonstration:** The students are asked to make objects go in a circle (i.e. make a rubber stopper or ball on a string go in a circle) and experience that a central force is necessary to counteract linear inertia.	**Inquiry Lesson**: The students determine variables that influence circular motion (i.e. speed, mass, and central force) by playing with stoppers of differing mass and string length.	**Inquiry Lab:** Students derive relationship for centripetal force using the traditional whirligig apparatus. (e.g., $a \propto v^2$ and $a \propto 1/r$ from which the relationship $a \propto v^2/r$ from which $F = mv^2 / r$ can be derived.
Constant Motion	**Discovery Learning:** Students are allowed to (a) "play" freely with motion detectors or (b) with ticker timers to understand constant motion. Students are asked to make meaning out of what is plotted on the graph.	**Interactive Demonstration:** Teacher asks for a volunteer to match a position-time graph. Students identify how graphical shape relates to the motion.	**Inquiry Lesson**: Students more deeply investigate the meaning of different shapes (they try to make shallow versus steeply angled lines). The significance of intercept and slope is discussed.	**Inquiry Lab:** Students derive a relationship for position and time using graphical methods without the assistance of a motion detector.
Work, Energy, and Conservation	**Discovery Learning:** Drop balls of different masses from different heights into the palm of one's hand. Note that the "magnitude of the impact" is proportional to both mass and speed of impacting body. Develop the concept that the energy of motion (kinetic energy) must be in some way a function of both mass and speed.	**Interactive Demonstration:** The teacher raises various masses different heights in an effort to get the students to understand the concept of work. In the end students should see work defined as $W = Fd = mgh$.	**Inquiry Lesson**: Students develop an understanding that the volume of a hole is proportional to the amount of work to dig it. Energy is the ability to do work. So, measuring the volume of a pit produced when a ball drops into clay should be proportional to its energy of motion. The question is how does one define the energy of motion (kinetic energy)?	**Inquiry Lab:** Students drop balls of varying mass into clay from varying release heights and measure the resulting volume of the pit so produced; counting the number of drop of water to fill it is useful. Find relationship between volume (proportional to work) and mass (fixed release height), and speed (fixed mass and a function of release height). Find that energy of moving ball at impact, KE, is proportional to m and proportional to the square of v. That is, $KE = mgh = (\text{constant})mv^2$. Graph mgh versus mv^2 to show that constant = ½
	Hypothetical Inquiry: Have students derive various kinematic laws on the assumption that energy is conserved. For instance, $W=E$; $Fd=½mv^2$; $mgh=½mv^2$; $2gh=v^2$; $2g(h - h_0) = v^2-v_0^2$; or more commonly $v^2-v_0^2 = 2ax$ where x_0 is taken to be 0. (See Wenning, 2009.)			

Fluid Pressure	**Discovery Learning:** Students immerse hands in water noting the growing pressure with depth. Students immerse partially filled inverted test tube in water bath and note the growing compression of air with increasing depth.	**Interactive Demonstration:** The instructor demonstrates 3-hole bottle. Students are asked to explain why (after making a prediction) water should shoot farther from lower hole than higher hole. They conclude they that pressure is a function of depth.	**Inquiry Lesson**: Students are asked to define the term pressure; $P = F/A$. Teacher presents the students with several examples of a constant amount of weight distributed over different surface areas.	**Inquiry Lab:** A glass funnel or thistle tube covered with a balloon and immersed to different depths in a fluid can be used to measure pressure differences if attach with a rubber tube to a U-tube. Students need to derive the relationship that pressure is proportional to depth. P = (constant)d.
	Hypothetical Inquiry: Students develop a hypothetical relationship of pressure as a function of depth, $P = \mathrm{f}(d)$, using dimensional analysis; relate to distance of squirt; derive the relationship $P = F/A = mg/A = \rho vg/A = \rho(Ad)g/A = \rho gd$ where d is the distance under the surface (depth) of the fluid of density ρ.			
Springs	**Discovery Learning:** Students develop a definition of equilibrium and displacement by playing with a suspended spring and masses. The teacher asks, "Is there a relationship between mass on the spring and how much it stretches? When no mass is on the spring, is the spring always stretched the same length?"	**Interactive Demonstration:** The instructor pulls a spring to a certain displacement and asks, "What happens when this is released?" This leads to the development of the concept of oscillation.	**Inquiry Lesson**: Develop the equation $F = -kx$ using a spring, masses, and a graphing program. Students should already know that $F = ma$ through previous lessons.	**Inquiry Lab:** Students derive the equation $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$, first through dimensional analysis and then through an experiment where students vary the mass and measure the frequency. Students are presented with a horizontal spring attached to a car on a track and a set of masses.
Ohm's Law and Electrical Circuits	**Discovery Learning:** Students are given batteries, wires, and light bulbs and asked to light one or more bulbs using one or more batteries. Socratic dialogues are used to develop the concepts of voltage, current, and resistance. Students are presented with simple series circuits with light bulbs of varying brightness and are asked to explain potential causes for the differences. Simple relationships relating voltage, current, and resistance are suggested.	**Interactive Demonstration:** The students are introduced to multi-meters as a means of measuring voltage, current, and resistance. Principles first proposed in the discovery-learning phase are examined. Focus is now placed an explanation of observations made during discovery-learning phase. The teacher proposes the analogy of water flowing in a pipe as a model for electrical flow. Students analyze alterative explanations and models.	**Inquiry Lesson**: The teacher uses a "think aloud" protocol and Socratic dialogue to help students derive a mathematical relationship between current and voltage for a series circuit containing a power supply and a single resistor. This is done a second and third time with 2 and then 3 roughly identical resistors in series. In effect, students derive various parts of Ohm's Law. Socratic dialogue is use to generate the more general form of the relationship $V=IR$.	**Inquiry Lab:** Students find relationships between resistors in series and then in parallel working in small groups. Before students begin working on parallel circuits, they are introduced to the concept of the inverse ohm or 'mho' (with the unit of 1/W or ℧) – a measure of electrical conductance or admittance – to make finding the parallel relationship simpler. The y-intercept is related to the system parameter – the value of the fixed resistor.
	Hypothetical Inquiry: In the area of pure hypothetical inquiry, students use Ohm's law and resistance relationships to explain why resistance in series is additive (conservation of energy) and why resistance in parallel is inversely additive (conservation of charge). In the area of applied hypothetical inquiry, students can be presented with an array of circuit puzzles. They form hypotheses as to how current flows in a given circuit using their understanding of conservation of charge and energy. Based on their understanding, they predict the direction and amount of current flow in each branch of various circuits. They then use meters to check their prediction and revise hypotheses in light of the evidence.			

Mass vs. Weight	**Discovery Learning:** Students develop an understanding of the difference between mass and weight. The teacher asks, "Why can astronauts jump so high on the moon?" Teacher asks how astronauts can be weightless in orbit but still have the same amount of matter as when on earth.	**Interactive Demonstration:** Ask student to describe ways of measuring mass and weight (i.e. using a pan balance or a spring scale). Pan balances are used to measure mass despite the value of "g" whereas spring balances are used to measure mass but only as a function of "g".	**Inquiry Lesson**: List factors that might affect an object's weight. Students will use spring scales to determine what factors listed actually affect an object's weight.	**Inquiry Lab:** Determine the relationship between the mass and weight of an object. $W = mg$. Conclude with an analysis of the constant of proportionality. This could be used as an introduction to the study of forces.
Conservation of Momentum	**Discovery Learning:** Students develop a conceptual understanding of momentum conservation by crashing toy cars into each other. One side of the cars has Velcro and one side does not so the students can study both elastic and inelastic collisions.	**Interactive Demonstration:** Develop the mathematical definition of momentum, $p = mv$ and the conservation of momentum $m_1v_1 = m_2v_2$. Students determine the momentum of an object by measuring its mass and velocity.	**Inquiry Lesson**: Using a Newton's Cradle, students determine the effects when a different amount of balls are pulled back. The teacher helps students understand that the momentum is conserved.	**Inquiry Lab:** Using an air track, students will create various collisions at different speeds, which are both elastic and inelastic. The mass of the cars will be measured and photogates will be used to determine the velocity of the cars both before and after the collision.
Specific Heat/Heat Capacity	**Discovery Learning:** Drop two equal masses of different materials at the same temperature (say iron washers and copper pennies) into hot water at the same temperature. Have the students observe the temperature after several minutes when equilibrium has been achieved. Are the resulting temperatures the same? If not, why not? Reverse the process putting hot objects into cool water and observe the temperature change. Ask the students, "What is happening?" in an effort to develop the concept of specific heat.	**Interactive Demonstration:** The teacher heats two different amounts of water and keeps heating time same to give the students understanding that amount of temperature change depends on the amount of matter given constant heating. That is, $\Delta T \propto 1/m$. The teacher then demonstrates that the change in temperature is proportional to the amount of heating. That is, $\Delta T \propto \Delta Q$.	**Inquiry Lesson**: Through Socratic dialogue, assuming that students know the concept of proportionality and inverse proportionality, the teacher puts students in a challenging situation in which students are asked to develop a mathematical relationship between specific heat, mass and change in temperature. That is, if $\Delta T \propto 1/m$ and if $\Delta T \propto \Delta Q$, then $\Delta T \propto \Delta Q/m$ and $\Delta T = \Delta Q/mc$ where c is a constant of proportionality. Thus, $\Delta Q = mc\Delta T$. Have students relate c to the specific	**Inquiry Lab:** By analyzing the relationship $\Delta Q = mc\Delta T$ students will see that if $m = 1kg$ and $\Delta T = 1^oC$, then $\Delta Q / m\Delta T \equiv c$ that confirms (indeed defines) that the specific heat is the amount of heat required to raise the temperature of one kilogram of a substance by one degree Celsius.

	Drop different masses of the same materials at room temperature (say 10 iron and 20 iron washers) into hot water at the same temperature. Have the students observe the temperature after several minutes – until equilibrium has been achieved. Are the resulting temperatures the same? If not, why not? Reverse the process putting hot objects into cool water and observe the temperature change. Ask the students, “What is happening?” in an effort to develop the concept of heat capacity.		heat of the material.	
Heat and Temperature	**Discovery Learning:** The teacher begins with a basic discussion of temperature. What is it? What does it tell us? Give examples of things at different temperatures. It is related to the size of a the object (comparing the temperature of two beakers containing different amounts of water at the same temperature.) Students develop the concept of heat by examining different amounts of water at the same temperature and asking questions about the amount ice required to cool each to the same temperature. Students will conclude that the larger beaker contains more heat energy thereby requiring more ice to cool it.	**Interactive Demonstration:** The teacher creates a puzzling situation by putting out three beakers (A, B and C) on a line containing hot, warm, and cold water respectively. Ask some randomly selected students to tell the nature of water by dipping their finger. Dipping their fingers from ‘A’ to ‘C’ and back to ‘A’ the students find water in beaker ‘B’ both hot and cold at a time which is practically not possible. Conversely, have students hold metal and wooden objects at room temperature and attempt to tell which is hotter and which is cooler of, indeed, if they are the same. From these demonstrations the teacher makes the students realize why we need a thermometer. Following this, this teacher introduces a thermometer and different temperature scales such as a Celsius and Fahrenheit.	**Inquiry Lesson**: Students more fully develop the their understanding of temperature by touching with same amount of water placed in three beakers at different temperatures – cold, room temperature, and hot. Ask what makes the water hot, lukewarm and cold? Place a single ink droplet into each beaker of calm water and ask the students to observe ink spread at different rates in different beakers. What makes the ink spread more rapidly in the hottest beaker? Through a Socratic dialogue, teacher should be able to help students conclude that temperature and particle speed are somehow related. This is, “The temperature is related to the average particle speed of the water.”	**Inquiry Lab:** The teacher provides students with Fahrenheit and Celsius thermometers and access to hot and cold running water. The teacher then asks the students to establish a relationship between degree Celsius and Fahrenheit scale using a graphical approach. They are directed to develop a data table showing both F and C temperatures for at least five widely ranging temperatures of water obtained by mixing. By plotting Fahrenheit versus Celsius temperatures, they should be able to obtain the following relationship: F = 9/5C+32.
	Hypothetical Inquiry: Using the fact that -40°C = -40°F and that F= 9/5C+32, have student show that a more general rule for conversion between the two systems of temperature measurement can be derived that states, “Add 40, multiply by 5/9 or 9/5, and subtract 40.” That is, 5(F + 40) = 9(C + 40). (See Wenning, 2001)			

Waves	**Discovery Learning:** Using a vertically wave model (oscillating rods) the definition of wave can be established. Ask the students how the disturbance propagates from one point to another. Do the components of the medium actually move from one point to another? Using a horizontally stretched Slinky (spring), have students investigate different types of waves (longitudinal and transverse). Students can develop simple relationships between tension and wave speed, etc.	**Interactive Demonstration:** Use two different sources such as a string and water in a ripple tank to produce transverse waves. Ask the students observe the movement of the string and a leaf place in ripple tank. From the observation ask them to develop definition of wave, the concept of amplitude, frequency, and wavelength, and time period. Using a waveform, ask the students to develop the relationship between speed, frequency and wavelength ($v = \lambda f$).	**Inquiry Lesson**: With the help of models, give the students concept of wave, ray, beam, wave front and wave let. Ask them to differentiate between mechanical and electromagnetic waves. How electromagnetic waves are different from mechanical waves? Develop activities to give the students concept of reflection, refraction, interference and diffraction of waves such as using a mirror and flashlight, pencil in a cylindrical glass, a hurdle in a ripple tank, etc.	**Inquiry Lab:** Using a glass tray in a way that a plane hurdle is placed inclined at one of the ends and sending plain waves towards the hurdle that upon striking with the hurdle reflect by making certain angle with the normal. Doing so students develop the law of reflection for water waves. Through similar experiments students develop law of refraction.
Waves on Springs/Ropes/Strings	**Discovery Learning:** Students develop an understanding of the nature of physical waves and wave propagation using a Slinky, rope, and string. Concepts of amplitude, frequency, period, and wavelength are developed using Slinky and given names using both transverse and longitudinal waves. Students relate period to frequency: $f = 1/t$. The effect of changing medium density is described based on wave propagation down a rope tied to a string. Students develop standing waves. (N.B. frequency and pitch are not identical, but will be treated as such here.)	**Interactive Demonstration:** Students observe the effect of changing tension, frequency (akin to pitch), and length on a stringed instrument to discover Mersenne's laws. Using Socratic dialogue and properly controlled demonstr-ations, the teacher gets the students to determine the general relationships between tension and frequency (e.g., the greater the tension the higher the frequency), between length and frequency (e.g., as length increase, the frequency decreases), and between linear density and frequency (e.g., the greater the linear mass density, the lower the frequency). The non-relationship of amplitude to other system variables is addressed.	**Inquiry Lesson**: Using a variable oscillator (whose frequencies are known) and a meter stick, student working under the guidance of the teacher conduct a controlled experiment to discover the inverse relationship between wavelength and frequency of standing waves on a string. Students conclude that the product of wavelength and frequency equals a constant. That is, $\lambda f = v$. Dimensional analysis is then used to show that the units of the constant are those of speed. Teacher draws parallels between v, d, and t, and wave counterparts to show that the constant, *c,* in the above equation equals speed of propagation. That is, $\lambda f = \lambda/t = d/t = v \equiv c$.	**Inquiry Lab:** Students use dimensional analysis and the statement $l = f(T, m, f)$ – this is, wavelength is a function of tension, linear mass density of the medium, and frequency – derived from observations to find the expected form of the relationship between variables. That is, $v = \lambda f = \sqrt{T/\mu}$. Students use an experimental set up in which they can control frequency, tension, and linear mass density of a string to confirm the expected form of the relationship.

Vibrating Columns of Air	**Discovery Learning:** Students are provided with bottles filled with different amounts of water, and asked to produce sound by blowing across the mouths of the bottles. Students work out the concept that the shorter the column of vibrating air, the higher the pitch of the sound generated. Students speculate as the source of the sound.	**Interactive Demonstration:** Students are introduced to various "slider toy" instruments or various brass and woodwind instruments and relate lengths over various open-ended air columns to the frequencies produced. Students compare and contrast the lengths of oscillating air columns and vibrating stings to see the parallels between propagation of oscillations and vibrations. Students use open-ended PVC pipes to play music by rapping pipes on palms of their hands.	**Inquiry Lesson**: Tuning fork held over top of an open-ended PVC pipe with one end immersed in water is used to show resonance phenomena. Students investigate ways to represent the motion of gas particles for standing waves in pipes. This is, they develop waveform representations.	**Inquiry Lab:** Students use knowledge of waveform representations and an experimental setup consisting of tuning fork (of known frequency) and PVC pipe (open ends on tube with one end immersed in water) to find resonance points to determine the speed of sound in air. Speed of sound in air is derived from the relationship $\lambda f = v$.
Projectile Motion	**Discovery Learning:** Students conduct a ball toss to determine qualitative relationships between of initial velocity (speed and angle) and the trajectory of the ball. (It is assumed here that students already have an understanding of kinematic relationships.)	**Interactive Demonstration:** Teacher demonstrates that motion in vertical and horizontal dimensions is independent with the use of a dual ball (projectile and free-fall) motion demonstration. Teacher demonstrates that the time up equals the time down. Using a launch mechanism that can provide consistent angles and launch speeds, students determine angle(s) that produces the greatest range of the projectile.	**Inquiry Lesson**: Using a launch mechanism that can provide consistent angles and launch speeds, qualitative relationships between time of flight and maximum altitude are determined based on vertical launch angle and speed. Teacher works with students to collect data and see that two different launch angles can be used with the same initial speed to achieve the same range (force of friction assumed to be 0).	**Inquiry Lab:** Students use their knowledge of kinematic equations in vertical and horizontal dimensions to predict the trajectory of a projectile given initial conditions including speed, la non-zero launch angle, and height differential between launcher and target. Before students conduct an experimental determination, they independently develop the traditional range equation. This is, $R = \frac{v^2}{g}\sin(2\theta)$ where v and g are given.

Thin Lens Formula	**Discovery Learning:** Students are introduced to a variety of convex lenses. Students note differences in thicknesses at the centers with respect to the edges. Students use lenses of different focal lengths as hand magnifiers. Students are directed to examine objects at the same distance with different hand magnifiers and to determine any differences. The major difference will be magnification; some lenses will greatly enlarge while others will enlarge things less. Students are instructed in the process of determining focal lengths of lenses using brightly lit objects at a distance. Students are asked to relate focal lengths to relative magnifying powers of the lenses. NB. Students find the magnification appears to be inversely proportional to the focal lengths of the lenses.	**Interactive Demonstration:** The teacher uses a convex lens to project brightly lit distant objects onto a view screen. This is done with a variety of different focal length lenses. Students see that longer focal length lenses produce larger (but dimmer) images. That is, some lenses are "stronger" and some lenses are "weaker." With Socratic questioning, students derive the principle that magnification seems to be inversely proportional to focal length. This will be tested during the follow-up inquiry lesson.	**Inquiry Lesson:** The principle derived during the interactive demonstration can be evaluated mathematically. Using a think aloud protocol and Socratic questioning, the teacher gets the students to measure the size of a standard object in a projected image and graph it relative to focal length. The students develop an inverse relationship between image size and focal length of the lens. The instructor then introduces the concept of the diopter (D = 1/f where f is expressed in meters; e.g., a 20cm focal length lens (0.2m) is equivalent to D = $+5m^{-1}$ = +5 Diopters (1/0.2). Note that a convex lens will have a negative focal length and therefore its strength well be negative, D = $-3m^{-1}$= -3 Diopters for instance).	**Inquiry Lab:** Students, using an optical bench, determine the relationship between di, do, and f for a single convex lens using diopters, D, as a unit of measure. NB: When students make a graph of D_i versus D_o, they get a linear relationship with a negative slope and a non-zero y intercept b. The focal length of the lens is a parameter of the system related to f. Replacing Di by 1/di, and Do by 1/do and identifying b with 1/f, students will find the thin lens formula: $\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$. While using diopters almost seems like cheating to some instructors it is highly unlikely that students will be able to linearize the multiply reciprocal relationship without using this approach.

Convection	**Discovery Learning:** Allow students to experience the phenomenon of convection in air by having them place their hands above a warm light bulb or candle flame. Heat a beaker full of water after sprinkling a number of small particles of pepper on the surface. Have the students note the direction of the water's motion. Replace the water with milk and sprinkle powdered cocoa on the surface. Heat the milk slowly over a hot plate and observe what happens. Light a candle. Hold a piece of paper above the candle but above the flame. Students will not how the rising hot air will ignite the paper. Put vegetable oil in a pan and slowly heat it from beneath with a flame or hot plate. Note the convection currents.	**Interactive Demonstration:** The teacher uses an aquarium to demonstrate the motion of air particles during convection. On one end of the aquarium set up a candle. On the other end of the aquarium set up a stick of incense. Keep the top open. The teacher asks students to predict what will happen if the candle and incense are lit and the cover immediately put on top of the aquarium. After students have written down their predictions (which should include direction of air flow as indicated by the incense), light the candle and incense and observe the results. Address any alternative conceptions that become evident. Students light a candle and darken the room. Using a bright projector lamp, shine light on the candle onto a projection screen. In a few moments the shadows of rising air will be visible over the candle. The flame will not have a shadow, but the air will (Schlieren imaging).	**Inquiry Lesson:** The teacher initiates a discussion about the cause of convection. Causes of convection are elicited. Temperature difference will most likely be the main explanation. "When things get hot, they rise. When they get cool, they sink." Using this explanation, ask students how this claim might be investigated. Using the same aquarium as before set up a bright heat lamp over a black piece of paper that lines the bottom of one end of the tank. Put a stick of incense at the other end. Tape thermometers to the two ends and topside wall of the tank. Light the incense. Place a transparent top on the tank, and turn on the lamp. Have students note temperatures where air is ascending, moving horizontally, and descending. Relate direction of motion to temperatures.	**Inquiry Lab:** Have students observe a Cartesian diver (a partially filled eye dropper in a water-filled two liter soda bottle works very well). Have students press the sides of the soda bottle and see what happens to the eyedropper; have students release the sides of the bottle and see what happens to the eyedropper. Introduce students to the concept of density if they are not already familiar with it. Have them measure the density of objects of various materials and compare to that of water. Have students relate the density of an object relative to water to determine if objects of higher and lower density sink or float.
	Hypothetical Inquiry: Have students explain the origin of the buoyant force. See Levels of inquiry: Hierarchies of pedagogical practices and inquiry processes. *Journal of Physics Teacher Education Online,* 2(3), February 2005, pp. 3-11. http://www.phy.ilstu.edu/pte/publications/levels_of_inquiry.pdf			