Conceptual Physics: A Curriculum

by: Keri Garver

Rationale

We are all forced to interact with the physical world around us daily. When we not only observe, but also understand the rules of nature that govern our physical world we are more fulfilled and well-rounded individuals. Traditional physics classes often alienate students with difficult mathematical derivations and computations. While the rules of nature can often be described mathematically, it is not the only way to describe them. Conceptual Physics emphasizes learning the fundamental principles of nature from which concepts can be derived. Mathematics is not necessary to understand that energy can neither be created nor destroyed--which is, in fact, one of the fundamentals of physics. In reality, the basic laws and rules, if understood, are what students use for the rest of their lives by applying them to myriad situations. Therefore, it is the goal of Conceptual Physics to facilitate students understanding of the rules of nature by learning their foundations, not by learning their mathematical derivations.

In addition, physics is the basic science. It is the foundation for biology, chemistry, geology, and all other sciences. Therefore, what one learns in Conceptual Physics will be the basis on which all of one's knowledge from the disciplines of science builds.

I intend to equip my high school physics students with a conceptual base of physical knowledge. From this base they can predict, control, calculate, measure, and observe their interactions with the physical world around them on a daily basis. This conceptual base will also foster their critical and analytical thinking for use throughout their lifetime.

Introduction

Conceptual Physics should be a full year class for junior or senior level high school students. For this class to be truly conceptual the laboratory experience is integral. Since high school classes are generally 45 minutes to an hour, one experiment may take two full class meetings. In addition, part of one class meeting prior to students conducting an experiment must be spent demonstrating the proper set-up and implementation for the students. And since each unit has at least one experiment, limiting the course to one semester would seriously inhibit complete understanding of the fundamental concepts due to a breakdown of the interdependent relationship between lecture and laboratory. Therefore, I do not feel the length of the course can be manipulated.

The order of the units within the course is not flexible, either. The units are where they are in the sequence due to the increase in complexity and sophistication as the year progresses. For example, the first unit, About Science, is a foundation for all subsequent units; hence it must be the first unit. Each unit is a prerequisite for the following units. For the course itself the only prerequisite is basic math since it is based on concepts, not

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complex mathematical computations.

In fact, what students have been taught and particularly the *way* they have been taught in other disciplines may cause some confusion for them in approaching science in a non-mathematical way. Most students are used to black and white—right or wrong—approaches to science and math. It is imperative that the teacher creates an environment that emphasizes new ideas or innovative ways to approach old ideas for a paradigm shift to occur. One effective way to foster such an environment for change is having students formulate their own theories before being taught the "correct" theory. Students are more likely to reevaluate their concept structures if they are consciously committed to their personal beliefs before learning the "correct" theory or witnessing the actual results (i.e. in an experiment). Likewise, students are more likely to grasp a concept if it is presented in a way that it is personally relevant to the students. In other words, present the phenomena as it occurs in nature—as the students have already observed for themselves—before it is presented in terms of a principle or law. Numerous examples are given in current conceptual physics textbooks and manuals.

I have based my course on the book *Conceptual Physics* by Paul Hewitt. I strongly recommend using a conceptual as opposed to a traditional text. If you are forced to use a traditional text be wary that those textbooks do not explain concepts in detail, but, instead, hope the math will do that for them, which is not often the case. Therefore, you must constantly stray from the book in lecture to emphasize the principles in words, not numbers. *Laboratory Manual in Conceptual Physics* by Bill Tillery is an excellent source for preparing experiments. Another good laboratory reference is *The Phenomena of Physics: A Conceptual Laboratory Manual* by Karen Johnston and Cecil Shugart. I must reiterate that the laboratory experience is an integral part of learning physics conceptually. By means of a close partnership between lecture and laboratory, this course attempts to answer the following question: What fundamental concepts of physics do we need to know to predict, control, calculate, measure, and observe our interactions with the rules of nature in the physical world?

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- Course Outline
  - Unit I: About Science
  - Unit II: Mechanics
  - Unit III: Properties of Matter
  - Unit IV: Heat
  - Unit V: Sound
  - Unit VI: Electricity and Magnetism
  - Unit VII: Light
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Each unit includes an introduction, ILOs, instructional foci, teaching strategies, and special notes

- Evaluation

Includes general instructional objectives

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Course Outline

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Intended Learning Outcomes

These are the ILO's for the entire course. There are also ILO's for each unit.

General Instructional Objectives	Specific Learning Outcomes
Knows terms	• identifies a definition of the term • identifies an example of the term • describes the procedure the term represents • states the concept or principle that fits the term • differentiates between the technical and the common meaning of a term
Understands the meaning of terms	• defines the term in their own words • identifies the meaning of the term when used in context • distinguishes between terms that are similar in meaning • relates terms to the concepts they represent • identifies similarities and differences between terms
Understands scientific concepts	• defines the concept in their own words • identifies an example of the concept • states hypotheses based on the concept • describes an experiment that illustrates the process • can list principals from which the concept was derived
Knows laboratory procedures	• identifies the laboratory equipment to be used • describes the steps to be followed in setting up the laboratory equipment

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	• lists the necessary precautions in handling and setting up the laboratory equipment • describes the steps to be followed in disassembling the laboratory equipment
Prepares a plan for an experiment	• identifies the problem to be solved • formulates questions relevant to the problem • formulates hypotheses in appropriate verbal /mathematical form • describes controls for variables • formulates experimental procedures • formulates observation and measurement procedures • describes the methods of data analysis • describes how the results will be presented
Demonstrates skills in laboratory work	• selects appropriate equipment for an experiment • assembles equipment correctly for an experiment • manipulates equipment as needed during the experiment • measures accurately with appropriate measuring device • follows safety rules in conducting experiment • uses materials without any superfluous waste • completes experiment within the time limits • cleans up equipment and returns it to its proper place • manipulates data appropriately • reports results in the appropriate way • distinguishes between valid and invalid conclusions
Participates in classroom	• listens attentively

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activities	• asks relevant questions • participates in classroom discussions • helps others when requested
Respects the scientific process	• favors evidence that results from scientific studies • seeks objectivity in the interpretation of evidence • changes opinions when evidence is contrary to beliefs • suspends judgement when evidence is inadequate • shows skepticism when statements are unsupported • bases ideas and opinions on the best scientific evidence available
Displays a scientific attitude	• demonstrates curiosity in identifying problems • demonstrates open-mindedness when seeking answers • suspends judgement until all evidence is available • respects evidence from credible sources • shows willingness to revise conclusions as new evidence becomes available

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Course Outline

I. About Science
- A. SI Units
  - 1. Length
  - 2. Mass
  - 3. Time
- B. Prefixes
- C. Conversion
- D. Significant Figures
- E. The Scientific Method

II. Mechanics
- A. Linear and Nonlinear Motion
- B. Newton's Laws of Motion
- C. Momentum
- D. Energy
- E. Rotational Motion
- F. Gravity

III. Properties of Matter
- A. Atomic Nature of Matter
- B. Solids
- C. Liquids
- D. Gasses and Plasmas

IV. Heat
- A. Temperature, Heat and Expansion
- B. Heat Transfer
- C. Change of State
- D. Thermodynamics

V. Sound
- A. Vibrations and Waves
- B. Sound
- C. Musical Sounds

VI. Electricity and Magnetism
- A. Electrostatics
- B. Electric Current
- C. Magnetism
- D. Electromagnetic Induction

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VII. Light
- A. Properties of Light
- B. Color
- C. Reflection and Refraction
- D. Light
  1. Waves
  2. Emission
  3. Quanta

VIII. Atomic and Nuclear Physics
- A. The Atom and the Quantum
- B. Atomic Nucleus and Radioactivity
- C. Nuclear Fission and Fusion

IX. Relativity
- A. Special Theory of Relativity
- B. General Theory of Relativity

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Unit 1: About Science

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Unit I: About Science

Introduction

This unit is one week long. We will discuss scientific measurements like the size of the earth, sun and moon, the distance between the earth and the sun and moon, the scientific method, and the International System of Units (SI Units). This unit serves as an orientation to a conceptual scientific course. The differences between traditional and conceptual physics should be addressed. Now is the time that an environment open to innovative ideas or novel ways to express old ideas should be established.

Intended Learning Outcomes

General Instructional Objectives (and corresponding Specific Learning Outcomes)	Unit Content
Knows terms Understands the meaning of terms Knows all laboratory procedures Prepares a plan for an experiment Participates in classroom activities Respects the scientific process Displays a scientific attitude Demonstrates skills in laboratory work	SI Units, significant figures, the scientific method

Instructional Foci

Experiment on graphing using measurements (SI Units) as data, experiment on ratios using measurements, SI Unit flow chart (fig. 1.1), personal timeline using accurate time scale (e.g. one centimeter = one year), class discussions, readings, homework

Teaching Strategies

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The teacher should make measurements relevant to the student by asking them to spontaneously call out everything they know of that equals a given mass, length and time in SI Units. For example, ask students what they can think of that is about one gram, 50 kg, 10 m, etc… The teacher should demonstrate on the board how the distances between the earth and the sun and moon are found. Through discussion, the class should explore different ways to plan an experiment. Hopefully students agree that the scientific method is a straightforward way to go about formulating an experiment and conducting it. Also, the teachers expectations of a scientific attitude should be discussed—what defines a credible source, when should judgement be made on the results of an experiment, etc…

Special Notes

1. All labs should be preceded by an in class demonstration by the teacher of the proper procedures. After viewing the demonstration, students' homework should be to prepare a plan for the experiment. Due to the time constraints of high school classes it is imperative that students have thought through the experiment before class. You, the teacher, need to know that they are aware of proper equipment set-up and safety precautions as well as appropriate hypothesis development, variable controls, and observation and measurement procedures.

2. Labs can be found in *Laboratory Manual in Conceptual Physics* by Bill Tillery.

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Unit 2: Mechanics

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Unit II: Mechanics

Introduction

This unit should be about six weeks. It should introduce the students to the concepts of mechanics. Mechanics can be broken down into linear motion, nonlinear motion, Newton's laws of motion, momentum, energy, rotational motion, gravity, and satellite motion. There is an enormous amount of information within this unit. Demonstrations and experiments are important facets in understanding all of the concepts packed into mechanics. Students should become more aware of the mechanics in nature that they face every day from driving a car to the motion of a satellite.

Intended Learning Outcomes

General Instructional Objectives (and corresponding Specific Learning Outcomes)	Unit Content
Knows terms Understands the meaning of terms	speed, velocity, acceleration, inertia, free fall, momentum, impulse, projectile, mass, weight, force, friction, impulse, angular momentum, work, power, potential and kinetic energy, torque, centripetal and centrifugal force, circular and elliptical orbits, efficiency, equilibrium, spring and neap tide, weightlessness, black hole, big bang, satellite, ellipse
Understands scientific concepts	motion is relative, velocity is a vector quantity vs. scalar quantity, free fall, elastic vs. inelastic collision, projectile motion, parabola, Newton's Laws, potential vs. kinetic energy, conservation of momentum and energy, center of mass and gravity, Kepler's Laws, law of universal gravitation, inverse-square law, gravitational field, escape speed
Knows all laboratory procedures Prepares a plan for an experiment Participates in classroom activities	All content

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Respects the scientific process Displays a scientific attitude Demonstrates skills in laboratory work	

Instructional Foci

Experiments: motion with a constant and a nonconstant velocity, the pendulum, Newton's second law, work and power, friction; demonstrations: free fall, and centripetal force; class discussions, quizzes, homework, readings, questions for thought from The Flying Circus of Physics by Jearl Walker

Teaching Strategies

For linear motion the teacher should begin with a general description of motion. Speed, velocity, and acceleration should then be introduced. The concept of free fall (acceleration due to gravity, g) can be introduced with a discussion of Galileo and the Leaning Tower of Pisa. Perhaps you could have your own leaning tower experiment by dropping different object from standing on top of the desk. This could then lead to a discussion about Aristotle and his theories in contrast to Galileo Galilei and his theories—noting the public dissatisfaction with Galileo's leaning tower experiment and Galileo himself.

Nonlinear motion should begin with the concept of relative motion. Then the concept of vectors versus scalars should be introduced, distinguishing velocity as a vector quantity as opposed to speed, which is a scalar quantity. From here the teacher should increase in complexity to projectile motion and circular motion. The space shuttle's projectile motion could be explored to make the concept relevant to the student, expanding on what they are already familiar with.

Building on the information presented in linear and nonlinear motion, the teacher should explore Newton's Laws of Motion. Many in class demonstrations and discussions should be utilized to ensure students understand the concepts presented here. The difference between mass and weight should be discussed. Force, inertia, and the conservation of energy are other key element to be taught in this section, also.

Next, the idea of combining inertia and motion to get momentum should be introduced. To produce a change in momentum either the velocity or the mass must be manipulated. Most commonly the velocity is changed due to a force acting on the object for a given time which is know as an impulse. Impulses such as the brakes of a car, the swing of a golf club or baseball bat, or the bouncing of a ball can all be discussed and demonstrated. The conservation of momentum should then be presented by discussing collisions—both elastic and inelastic—using examples of cars and billiard balls as common examples.

Then we begin the study of energy. Energy is difficult to define because it is a "thing" as well as a process. Everything has energy, but we only observe it when it as it is being transformed. In other words, we see it in forms—in the form of the food we eat, in the form of electromagnetic waves we feel as heat from the sun, in the form of photosynthesis for plants, etc... These aspects of energy should be

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introduced before exploring related concepts, like work. Mechanical energy, such as potential and kinetic energy should then be compared and contrasted. Of course one of the fundamentals of physics, the concept of the conservation of energy, should then be taught, giving examples of how cars consume more fuel when the air conditioner, lights, and radio are on—nothing is free. Then the teacher can discuss energy used for machines and energy used for life—what are the similarities and differences?

There is much more to nonlinear motion and Newton's Laws than previously discussed. Rotational motion builds on these principles to explain the rotation of an object about an axis. The teacher should discuss rotational inertia and how torque effects that inertia. The center of mass and center of gravity as well as centripetal and centrifugal force should be demonstrated. The classic demonstration of a bucket full of water rotating around your arm (swinging it) is ideal in demonstrating centripetal and centrifugal force. And of course the exploration of this section should end with a discussion of the conservation of angular momentum.

To introduce this section on gravity the teacher should discuss Johannes Kepler and Kepler's laws of planetary motion. He/she should then go on to discuss Newton's law of universal gravitation. Then weight and weightlessness could be introduced with a discussion on taking a scale into an elevator (what does the scale read when stationary, when moving, and when free falling) and astronauts. Following this, the ocean tides should be explained. Gravitational fields and black holes should be taught as a precursor to the next section on satellite motion.

Current satellites—their forms and functions—should be presented as an introduction to the final section of mechanics (at last!), satellite motion. Newton's ideas of the falling apple and "falling moon" should be studied. Basic satellite motion and escape speed should also be explored. Finally, what would a section of mechanics be without a discussion of energy conservation and satellite motion?

Special Notes

1. All labs should be preceded by an in class demonstration by the teacher of the proper procedures. After viewing the demonstration, students' homework should be to prepare a plan for the experiment. Due to the time constraints of high school classes it is imperative that students have thought through the experiment before class. You, the teacher, need to know that they are aware of proper equipment set-up and safety precautions as well as appropriate hypothesis development, variable controls, and observation and measurement procedures.

2. Labs can be found in Laboratory Manual in Conceptual Physics by Bill Tillery.

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Unit III: Properties of Matter

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Unit III: Properties of Matter

Introduction

It is difficult to conceptualize something as small as an atom, and, yet atoms are more pervasive than any thing we know. All matter is made up of atoms. In fact, all matter is made up of just 109 distinct atoms! In studying the properties of matter we will explore the atomic nature of matter in its four states—solids, liquids, gasses, and plasmas. This unit is divided into three sections: atomic nature of matter, solids, liquids, and gasses and plasmas. Studying this will take approximately two and a half weeks.

Intended Learning Outcomes

General Instructional Objectives (and corresponding Specific Learning Outcomes)	Unit Content
Knows terms Understands the meaning of terms	atom, Avogadro's number, molecule, density, elasticity, buoyant force, plasma, surface tension, capillarity, compound, mixture, antimatter
Understands scientific concepts	atomic structure, Brownian motion, states of matter, the periodic table, atomic bonding, scaling, crystal structure, Archimedes' Principle, Pascal's Principle, Boyle's Law, Bernoulli's Principle, Hooke's Law, principle of flotation
Knows all laboratory procedures Prepares a plan for an experiment Participates in classroom activities Respects the scientific process Displays a scientific attitude Demonstrates skills in laboratory work	All content

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Instructional Foci

Experiments: Archimedes' principle, Hooke's Law; demonstrations: Bernoulli's principle, crystal structure using blocks, principle of flotation, surface tension, capillarity, compound, mixture; class makes their own "periodic table" from different shapes of pasta, class discussion, homework (including measuring the weight of their car), quizzes, readings, questions for thought from the Flying Circus of Physics

Teaching Strategies

The first section of this unit, the atomic nature of matter, should begin with a discussion of atoms. The size, number, and agelessness of atoms are particularly important concepts to get across to the students. In addition, the teacher should discuss how atoms jiggle perpetually (Brownian motion). Atoms combine to form molecules. When studying molecules it may be helpful to use models of molecules (water—H_2O, methane—CH_4, ozone—O_3) made of styrofoam balls or purchased from science demonstration supply catalogs. With models students quickly realize that atoms are joined in well defined ways to form molecules. Also, using models is a good way to introduce molecular and atomic masses. Then more complex models can be used to illustrate the difference between elements, compounds, and mixtures. Physical examples of elements, compounds and mixtures should be demonstrated also. Gold, water, and salt with sand are good examples of each, respectively. A brief discussion of the structure of the atom should follow this demonstration. Once students have a basic understanding of the atomic structure, and before you introduce them to the periodic table, an in class project of forming their own organizational system on a chart should be done. For example, students could be asked to organize different shapes of pasta into a pattern to fit a chart. This causes students to make a conscious commitment to an organizational scheme. Hopefully they are then more likely to revise their scheme to the scheme of the periodic table. Otherwise, without introducing organizational schemes, they often lose the meaning of the ordered nature of the periodic table. Following the discussion of the periodic table should be a brief discussion of the different states of matter and antimatter.

The next section explores the solid state of matter. This discussion should begin with crystal structure, which is what many solids are made of. Blocks can be purchased which illustrate each of the crystal structures, but too much emphasis should not be placed on this. Styrofoam balls arranged to represent, for example, a crystal of sodium chloride (NaCl) can just as easily be used. Then a discussion of density as related to crystal structure (spacing of the atoms) and mass would be appropriate. Changes in the arrangement and bonding of atoms in a material resulting from a deforming force are know as elasticity. When studying elasticity, Hooke's law should be demonstrated using springs with varying weights (illustrating that the amount of stretch is proportional to the force applied or weight). This discussion will naturally lead to the discussion of tension and compression. Tension and compression rules can be illustrated using arches and domes in architecture. This is why the Astrodome in Houston does not need any columns to support it. Other examples are the Capitol, Eskimo igloos, Roman aqueducts, and the Jefferson Monument. Finally, there should be a brief discussion of scaling.

The liquid state of matter will be explored in this section. We will begin with a discussion about pressure in a liquid. An illustrative example is swimming under water—as you increase in depth you feel an increase in pressure against your eardrum. In addition, when you try to pick someone or something up under water it seems lighter than when you try to lift it out of the water or above the surface. This is due to buoyant force, which depends on the volume of the displaced object, **not** the weight of the displaced object. A demonstration for this and Archimedes' Principle

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follows: using a beaker full of water immediately next to an empty one being held up by a scale, lower a weight, being held up by a scale, into the beaker of water and watch as the scale attached to the weight decreases as the water pours into the empty beaker, and its weight increases. Notice the initial weight of the scale is equal to the weight of the immersed weight plus the weight of displaced water (Archimedes' Principle). Then demonstrate and discuss the density effects on submerged objects if the object is (1) denser than the fluid (a penny in water), (2) less dense than the fluid (a piece of styrofoam in water), (3) equal density to the fluid (a fish). This will naturally lead to a discussion about flotation. Talk about canoes or ships that, when weighing more float lower (displace more) in the water than when empty or weighing less (displace less)—a floating object displaces a weight of fluid equal to its own weight. Then discuss Pascal's Principle, an example of which is an automobile lift. Surface tension and capillarity will be the next topics of study. An excellent example relevant to students' lives is that of soap weakening the cohesive forces between water molecules, hence reducing surface tension. To illustrate this interaction, mix oil and water in a jar then calculate the time it takes for them to separate. Now add soap to the mixture and re-mix it, calculating the time it takes to separate the oil from the water. It should take much longer with the soap in the mixture since soap breaks the surface tension around each oil (dirt) particle. This is what allows the water to surround the dirt particle and carry it away with rinsing. To illustrate capillarity pass around different diameter test tubes filled with water and not the capillary action in each. Also, dip the tip of a paper towel in water and notice how the water seeps up higher than the water level due to capillary action.

In the final section of this unit we will explore gases and plasmas. The atmosphere is a relevant illustration of gases doing their thing. The teacher should also discuss atmospheric pressure, barometers and Boyle's Law. An excellent homework exercise for understanding the concept of pressure is to have the students measure the force or weight of their car using the area of and pressure in their tires. Give students a large pieces of graph paper in square centimeters. They should trace the area of a tire, assuming the other four tires have the same area, and determine the pressure in the tire (by using a pressure gauge or by assuming the pressure in the tire is as it should be according to the pressure requirement of the tire). They should then convert the area traced on the graph paper from square centimeter to square inches. This number of square inches multiplied by the pressure of the tire in pounds per square inch will give them the force or weight of their car! Then discuss the buoyancy of air, which is just like the buoyancy of water, but in air. Following that should be a discussion of Bernoulli's Principle. Only after the students have some grasp of the this principle should a demonstration of it in action be given. The demonstration could use a ball tied to a string that is then held under a steam of running faucet water. Then pull the string away from the steam and notice the ball stays in the running water. This is, of course, due to the decrease in pressure from the increase in speed of the water causing the ball to seek the area of lesser pressure or be pushed from the higher pressure surrounding air into the lower pressure stream of water. Airplanes, tornadoes (and torn off roofs), and spin on a tennis ball are also relevant applications of Bernoulli's Principle. This section will be concluded with the discussion of plasma as the fourth state of matter. A discussion of fluorescent lamps, which use a plasma consisting of low-pressure mercury vapor, would be appropriate.

Special Notes

1. <u>All</u> labs should be preceded by an in class demonstration by the teacher of the proper procedures. After viewing the demonstration, students' homework should be to prepare a plan for the experiment. Due to the time constraints of high school classes it is imperative that students have thought through the experiment before class. You, the teacher, need to know that they are aware

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of proper equipment set-up and safety precautions as well as appropriate hypothesis development, variable controls, and observation and measurement procedures.

1. Labs can be found in *Laboratory Manual in Conceptual Physics* by Bill Tillery.

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Unit IV: Heat

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Unit IV: Heat

Introduction

Heat is not the same as temperature. Heat is the energy that flows due to a difference in temperature. If I put my cold hands in front of the warm fire, heat flows from the fire and is transferred to my hands. Temperature is related to the average kinetic energy of the molecules within the material. The molecules in ice have a very small kinetic energy, whereas the molecules in boiling water have a rather large kinetic energy. This unit will further explore the difference between heat and temperature in the first section. The next section will discuss different ways to transfer heat, followed by a section on the changes of states in matter we just learned due to heat (or lack thereof). In the final section the laws of thermodynamics will be explored. About two and a half weeks should be devoted to this unit.

Intended Learning Outcomes

General Instructional Objectives (and corresponding Specific Learning Outcomes)	Unit Content
Knows terms Understands the meaning of terms	temperature, absolute zero, heat, internal energy, conduction, convection, radiation, evaporation, condensation, boiling, regelation, entropy
Understands scientific concepts	specific heat capacity, Newton's law of cooling, solar constant, solar power, the greenhouse effect, the thermos bottle, geysers, changes of state, absolute zero, Laws of Thermodynamics, adiabatic process
Knows all laboratory procedures Prepares a plan for an experiment Participates in classroom activities Respects the scientific process Displays a scientific attitude Demonstrates skills in laboratory work	All content

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Instructional Foci

Experiments: specific heat, coefficient of linear expansion of metals, thermometer fixed points; demonstrations: dented Ping-Pong ball in boiling water, heated tile vs. heated wood (at same temperature), black box, thermos bottle, paper wrapped around an iron bar exposed to flame; homework, quizzes, class discussion, questions for thought from the Flying Circus of Physics

Teaching Strategies

The first section of this unit should begin with a discussion of temperature as compared to heat (including specific heat). Then discuss using heat to increase the temperature of a material that, in most cases, will then expand. A thermostat is an everyday example of this concept in use. Place a dented Ping-Pong ball in boiling water and watch it release its dent due to expansion. Discuss the anomaly, water, when its temperature is increased from ice to above 4° C (should expand with an increase in temperature, but contracts slightly before expanding due to collapsing of ice crystals).

The second section explores heat transfer. The exploration begins with conduction. To demonstrate how conduction differs according to the material being heated, place a tile and a piece of wood on the same burner and note the differences in temperature. Then discuss convection. Possible topics to discuss related to convection are why warm air rises and why expanding air cools. Then study the third form of heat transfer, radiation (radiant energy). Examples of heat radiation are infrared waves from a fireplace and infrared waves from the sun. But we also reflect some of the radiation that hits us as well as radiate our own energy, therefore maintaining some balance. To demonstrate what happens when all radiation incident on an object is absorbed paint the inside of a box white and place a small hole on one side. When the lid is on the box it appears black inside the hole because all radiation is absorbed. But, when the lid is removed students will see that it is actually white inside now that radiation is allowed to be reflected and absorbed. This same concept explains why the pupils in our eyes appear black unless they are illuminated directly—like with a camera flash, in which case they appear pink. Also discuss the imbalance of radiation flux at night that we see in the form of frost or just cooler temperatures. Then study Newton's law of cooling, which states that an object at a different temperature than its surroundings will eventually reach thermal equilibrium with the surroundings. On an environmental note, students should be taught about the greenhouse effect, the excess heat problem, and solar power. A likely conclusion to this unit is a demonstration of the thermos bottle, which inhibits all three methods of heat transfer to some degree. An obvious demonstration is placing a hot or cold liquid of a known temperature into a thermos and into a cup that is not insulated and measuring the temperature of each at the end of class time.

Change of state is the central topic of the third section. The teacher should explore each of the changes of state, including evaporation, condensation, and boiling, melting and freezing. Water is an easy source to illustrate each of the different states (geysers are excellent examples of boiling). Also, pressure induced freezing (regelation) as well as energy induced freezing should be discussed. The changes in energy associated with the changes in states should be studied.

In the final section of the unit on heat, thermodynamics will be studied. Thermodynamics is the study of heat and its transformation to mechanical energy. First, the teacher should discuss the lower limit of temperature, absolute zero on the Kelvin scale (as opposed to no known upper limit on the temperature scale). Then the law of conservation of energy can be applied to thermal systems as the first law of thermodynamics. The concept of adiabatic processes, in which

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mechanical work is done to increase the internal energy of a system—following the first law of thermodynamics, should be discussed. Two concrete examples of an adiabatic process which students should be familiar with are the bicycle pump and the compression and expansion of the gases in cylinders of an automobile engine. The teacher may also want to discuss changes in weather and the first law (change in temperature ~ change in pressure). For the second law of thermodynamics, which states that heat will only flow from hot to cold, not the other direction, can be applied to heat engines, which change internal energy into mechanical energy. The second law of thermodynamics, based on the heat engine, can be restated as follows: natural systems tend to proceed toward a state of greater disorder. For example, a closed jar full of gas molecules, when opened will diffuse the gas molecules into the air and not vice versa. The teacher should then conclude this unit with a discussion of the definition of this amount of disorder, entropy.

Special Notes

1. All labs should be preceded by an in class demonstration by the teacher of the proper procedures. After viewing the demonstration, students' homework should be to prepare a plan for the experiment. Due to the time constraints of high school classes it is imperative that students have thought through the experiment before class. You, the teacher, need to know that they are aware of proper equipment set-up and safety precautions as well as appropriate hypothesis development, variable controls, and observation and measurement procedures.

1. Labs can be found in *Laboratory Manual in Conceptual Physics* by Bill Tillery.

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Unit V: Sound

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Unit V: Sound

Introduction

Sound waves are all around us most of the time. They provide us with a major source of communication (speech), a source of enjoyment (music), and a source of irritation or distraction (noise). But do you know what sound *is*? This unit is divide into three sections: vibrations and waves, sound, and musical instruments. It should take two weeks to explore this unit.

Intended Learning Outcomes

General Instructional Objectives (and corresponding Specific Learning Outcomes)	Unit Content
Knows terms Understands the meaning of terms	transverse and longitudinal waves, sine curve, amplitude, wavelength, frequency, hertz, period, wave speed, interference pattern, shock wave, infrasonic, ultrasonic, compression, rarefaction, reverberation, refraction, forced vibration, standing wave, bow wave, speed of sound, resonance, beats, pitch, loudness, modulation, partial tone, harmonic
Understands scientific concepts	wave motion and speed, interference pattern, sonic boom, Doppler Effect, natural frequency, carrier wave, amplitude and frequency modulation (AM and FM), fundamental frequency
Knows all laboratory procedures Prepares a plan for an experiment Participates in classroom activities Respects the scientific process Displays a scientific attitude Demonstrates skills in laboratory work	All content

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Instructional Foci

Experiments: standing waves, speed of sound in air; demonstrations: tuning fork in large room—note interference patterns (rarefactions and compressions add and subtract in different areas to created different loudness), slinky (transverse and longitudinal waves), rope (nodes), look at sound waves on an oscilloscope, two combs to represent beats; homework—make a musical instrument (in class listen to it using the oscilloscope, quizzes, class discussion, questions for thought from the Flying Circus of Physics

Teaching Strategies

To begin the unit on sound, the teacher should discuss vibrations and waves. The period of a pendulum as discovered by Galileo, should be discussed. Following this should be a description of waves (including simple harmonic motion, sine curves, amplitude, and frequency. Once these basic terms have been taught, wave motion and wave speed may be studied. To distinguish between transverse and longitudinal waves a slinky attached to the wall should be used. By pushing and pulling the slinky you create a longitudinal wave. By shaking the end of the slinky up and down a transverse wave is created. Then interference patterns, where two waves overlap, canceling in places and reinforcing in places, should be discussed. To demonstrate standing waves, which are caused by interference, tie one end of a rope to the wall and shake the free end until standing waves of one, two and three nodes are produced. When the motion of the receiver or transmitter of sound moves there is a change in frequency. This is called the Doppler effect. One relevant example of the Doppler effect is the changing pitch of a car (ambulance, fire truck, etc…) horn as a car drives by a stationary person. If something were to move at a speed equal to the speed of the wave (sound) a wave barrier is produced. This happens when an aircraft travels at the speed of sound. A great deal of thrust is necessary to overcome the wave barrier. However, once overcome the aircraft can fly faster than the speed of sound—supersonic. When something moves faster than its wave speed it produces a pattern of waves know as bow waves, which make the shape of a "v". In three dimensions this is known as a shock wave, which produces waves in the shape of a cone. Supersonic aircraft produce this and when it reaches listeners on the ground they here it as a loud crack or sonic boom.

Now to dissect what we hear, sound. The teacher should begin by exploring where sound comes from. The answer is usually sound comes from vibrations of material objects. He/she should talk about the medium through which sound travels, the type of waves most commonly produced, the speed of sound, and the frequency of waves. Sound can also be reflected, which we call an echo or, in terms of multiple reflections, reverberation. An ultrasound, which most students should have at least heard of, is due to the reflection and refraction of high-frequency sound. The small relatively small amount of energy needed to produce sound should be discussed. Combining forced vibrations that match an objects natural frequency causes a dramatic increase in amplitude known as resonance. An example of resonance sometimes occurs when swinging on a swing. If somebody gives a small push to the swinger in rhythm with the frequency of the swinging motion, the amplitude is greatly increased. On the contrary, when the crest of a wave meets the trough of a wave their amplitude decreased to almost zero. This is called interference. Interference can be demonstrated by striking two tuning forks out of rhythm in a large room. If students walk around or sway their heads back and forth they will hear soft areas and loud areas produced from compressions and rarefactions adding and subtracting. If the two tones are of slightly different frequencies they will vary periodically in loudness. This is known as beats. Overlapping two combs of different teeth spacing will illustrate this phenomenon.

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Finally, the last section of this unit will explore musical sounds. Pitch, loudness, and quality should be defined and discussed. You are then ready to study musical instruments and musical scales. Once these topics have been introduced students should be asked to create their own musical instrument, be it a blade of grass or a rubber band guitar. Students should bring their homemade musical instruments as well as any real musical instruments to class to be viewed in terms of frequency on an oscilloscope. A brief study of how compact discs work would be an interesting way to conclude the unit on sound.

Special Notes

1. All labs should be preceded by an in class demonstration by the teacher of the proper procedures. After viewing the demonstration, students' homework should be to prepare a plan for the experiment. Due to the time constraints of high school classes it is imperative that students have thought through the experiment before class. You, the teacher, need to know that they are aware of proper equipment set-up and safety precautions as well as appropriate hypothesis development, variable controls, and observation and measurement procedures.

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Unit VI: Electricity and Magnetism

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Unit VI: Electricity and Magnetism

Introduction

Only do we realize how important electricity is to our daily functions when it unexpectedly goes off. And a related phenomena to electricity is magnetism. They combine to form one of the four fundamental forces, electromagnetic force. In this unit there are four sections: electrostatics, electric current, magnetism, and electromagnetic induction. Covering these topics should take about 3 weeks.

Intended Learning Outcomes

General Instructional Objectives (and corresponding Specific Learning Outcomes)	Unit Content
Knows terms Understands the meaning of terms	charging by contact and induction, capacitor, conductor, insulator, semiconductor, superconductor, electrically polarized, electrostatics, electric field, electric potential, electric current, resistance, direct and alternating current (dc and ac), electric power, magnetic field, magnetic domains, electromagnets, electromagnetic induction, generator, transformer
Understands scientific concepts	conservation of charge, electric potential energy, Coulomb's Law, Ohm's Law, direct and alternating current, series and parallel circuits, magnetic domains, electromagnets, magnetic force, Earth's magnetic field, Faraday's Law, Maxwell's counterpart to Faraday's Law
Knows all laboratory procedures Prepares a plan for an experiment Participates in classroom activities Respects the scientific process Displays a scientific attitude Demonstrates skills in laboratory	All content

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work	

Instructional Foci

Experiments: static electricity, series and parallel circuits, magnetic fields; demonstrations: charging by friction—use rabbit fur to charge a rubber rod and styrofoam to charge plastic strips, charging by induction—use insulated metal spheres to induce charge on plastic rod, balloon sticks to wall due to polarization, hair standing on end using a Van de Graaff generator, simple circuit, magnets with iron filings, listening to magnetic domains align using an amplified stethoscope; homework—make a citrus cell (battery) using a paper clip, a copper wire, and a lemon, quizzes, class discussion, questions for thought from the Flying Circus of Physics

Teaching Strategies

To begin the study of electrostatics, electrical forces and electric charges should be discussed and demonstrated. The demonstration uses rabbit fur to induce a charge on a rubber rod. In addition, styrofoam is used to induce a charge on a plastic strip. The charged objects are then brought near uncharged object to observe the phenomena of electric forces and electric charges. This demonstration can also be used to show the basic concept derived from Coulomb's Law. Then the teacher could try to charge a metal rod while holding it to introduce conductors, semiconductors, and insulators (the metal rod will not hold a charge because it is a conductor, so the charge will flow right into you). In addition, this demonstration along with the Van de Graaff demonstration can be used to illustrate the different means of charging an object: charging by contact (friction) and charging by induction. Charging by induction using the Van de Graaff generator can also be used to demonstrate charge polarization in insulators. Charging a balloon by contact and sticking it to a wall is another example of polarization. Then the teacher should study the forces that exist between things that are not in contact—electric fields. They should discuss electric shielding and electric potential. Then the teacher can refer back to the Van de Graaff generator as one device for storing electric energy along with capacitors.

Electric current is the flow of charge. The flow of charge can be illustrated using a simple circuit. In exploring the simple circuit, voltage sources and resistance should be discussed. Then the relationship between the flow of charge (current), resistance, and voltage can be related using Ohm's Law. You might ask students to think about why it is that a bird can sit on a wire of high potential and not be harmed (answer: no voltage *difference* between its legs). Direct current and alternating current should be defined. This should lead to a discussion of the speed and source of electrons in a circuit. For example, how is it that turning on a light switch almost instantaneously produces light? Do electrons flow that fast? The answer is that current is not literally electrons flowing, but, rather, it is the electric field (which travels at nearly the speed of light) established inside the conductor (wire) once the switch is flipped, which nudges the randomly moving electrons in the right direction. Now that students know how their household switches work, they should study how they are configured to work the way they do. Parallel and series circuits should be demonstrated.

The section on magnetism should begin with a discussion on magnetic forces, poles and fields. The teacher should demonstrate how like poles repel, and opposite poles attract and how magnetic fields behave using a magnet and iron filings. Placing unmagnetized iron near a magnet can

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magnetize it. In doing so, large clusters of randomly oriented atoms in the unmagnetized iron interact with the magnetized iron by lining up with each other. These large clusters are called magnetic domains. Students can actually listen to the magnetic domains aligning with an amplified stethoscope. Then the interaction between electric currents and magnetic fields, known as electromagnetism, should be discussed. Practical applications of this relationship such as doorbells and magnetically levitated trains should be discussed. In addition, magnetic force on moving charged particles and current-carrying wires should be studied. Using the right hand rule to determine the relationship between the vectors of the magnetic field, the force, and the direction of current should be demonstrated for the students. To conclude the section on magnetism, the earth's magnetic field should be discussed. How the change in the magnetic field over time allows us to date oceanic sediments through geologic time should be presented. In addition, a discussion of aurora borealis and aurora austrealis would be interesting and appropriate.

The final section of the unit should begin by defining and discussing electromagnetic induction, which is summarized by Faraday's law. Then the application of electromagnetic induction in a generator and in a motor can be compared and contrasted. Nikola Tesla and George Westinghouse put electromagnetic induction to use with a turbogenerator, used to generate enough electricity to light entire cities. The teacher should then discuss transformers and their application of electromagnetic induction. A precautionary note about self-induction when using electromagnets would be appropriate if the teacher intends the students to use any electromagnets. Finally, the equal and opposite law of Faraday's law, know as Maxwell's counterpart to Faraday's law, should be studied.

Special Notes

1. All labs should be preceded by an in class demonstration by the teacher of the proper procedures. After viewing the demonstration, students' homework should be to prepare a plan for the experiment. Due to the time constraints of high school classes it is imperative that students have thought through the experiment before class. You, the teacher, need to know that they are aware of proper equipment set-up and safety precautions as well as appropriate hypothesis development, variable controls, and observation and measurement procedures.

1. Labs can be found in *Laboratory Manual in Conceptual Physics* by Bill Tillery.

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Unit VII: Light

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Unit VII: Light

Introduction

The American Heritage Dictionary definition of light is electromagnetic radiation that has a wavelength in the range from about 4,000 (violet) to about 7,700 (red) angstroms and may be perceived by the normal unaided human eye. We will study this light in depth, as well as light that cannot be seen by the human eye. This unit will take approximately three weeks and will cover the sections that follow: properties of light, color, reflection and refraction, light waves, light emission, and light quanta.

Intended Learning Outcomes

General Instructional Objectives (and corresponding Specific Learning Outcomes)	Unit Content
Knows terms Understands the meaning of terms	electromagnetic waves, electromagnetic spectrum, transparent and opaque materials, umbra, penumbra, solar and lunar eclipse, additive and subtractive primary colors, complementary colors, reflection, transmission, refraction, dispersion, interference, diffraction, critical angle, total internal reflection, virtual and real image, aberration, polarization, excitation, incandescence, fluorescence, phosphorescence, laser, photoelectric effect, complementarity
Understands scientific concepts	solar and lunar eclipse, seeing light (the eye), rules for color mixing, why the sky, sunset, clouds, and water are the color they are, Fermat's principle of least time, law of reflection, converging and diverging lenses, Huygen's Principle, emission and absorption spectra, spectroscope, quantum theory, Planck's Constant, photoelectric effect, Uncertainty Principle
Knows all laboratory procedures Prepares a plan for an experiment	All content

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Participates in classroom activities Respects the scientific process Displays a scientific attitude Demonstrates skills in laboratory work	

Instructional Foci

Experiments: reflection and refraction, lenses; demonstrations: shadows (penumbras and umbras), use different colors of light to illuminate an object and note how the color changes, make spectroscopes as a class, lenses, dispersion through a prism, diffraction grating, polaroids (material in polarized sunglasses); homework, quizzes, class discussion, questions for thought from the Flying Circus of Physics

Teaching Strategies

The unit on light should begin with a section on the properties of light. Electromagnetic waves and the electromagnetic spectrum are a good place to start. Then transparent versus opaque materials should be discussed. Before conceptual physics class one might have thought a shadow is a shadow. But we are here to tell you that a total shadow is called an umbra and a partial shadow is called a penumbra. These can be demonstrated by placing an object between a white wall and a light source and moving it further and further from the wall. Other examples of these shadow parts are solar and lunar eclipses. A brief exploration of how the human eye functions should be undertaken.

Next, the teacher should focus on color. Selective reflection (or transmission in the case of transparent objects) of light is what causes an object to have color. If light in various parts of the spectrum illuminates an object they will appear to be brown or black except in the part of the spectrum which they reflect. This can be demonstrated in front of the class using different colors of light on an object. Then the teacher should discuss mixing colored light, including additive and subtractive primary colors. This will help in understanding why the sky is blue, why sunsets are red, why clouds are white, and why water is greenish blue.

Reflection, refraction, and Fermat's principle of least time should be defined in the beginning of the third section. One example of refraction is the apparent mirage that appears ahead of you when driving on a hot, sunny day (due to warmer, less-dense air near the surface of the road refracting sky light). Other causes of refraction should be discussed. The concept of total internal reflection should also be taught. Examples of different lenses and the image they produce should be demonstrated before the class.

Light, like sound, has some of the properties of a wave. Light wave fronts are made up of tinier wave fronts, which is known as Huygens' Principle. Then the idea of diffraction can be introduced by observing light through a slit and noting the diffracted light on the wall. Similar to the interference observed when listening to sound waves is the interference pattern of overlapping light waves. This can be demonstrated similar to diffraction, but using a double slit instead. To illustrate that light waves are transverse and not longitudinal the teacher must polarize the light by

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using a polaroid sheet. Using a single polaroid sheet can block one component (horizontal and vertical) of light. Sunglasses block the horizontal component of light, thus reducing glare from reflected light (off of water). The teacher could then discuss colors by transmission through polarizing materials, three dimensional viewing, and holography if desired.

Light emission involves the transition of electrons from higher to lower energy states within an atom, which is called excitation. Emission spectra of different light sources (phosphorescent, fluorescent, and incandescent) can be viewed through a simple spectroscope made in class by purchasing a kit (including a tube with a slit on one side and a hole on the other covered by a diffraction grating. The difference between incoherent and coherent light must be discussed before learning about the laser. Applications of the laser are many, many—a very common one is the bar code.

Contrary to the wave-like nature of light is its particle-like nature of light. Light is unique that it acts like a wave and a particle, which have mutually exclusive properties. We will now explore the quantum theory of light. In the world of quantum physics, energy is quantized which means it comes in discrete bundles, no half or partial bundles. One quanta of light is a photon. Knowing this, the photoelectric effect can be discussed. Quanta, although considered a particle, do exhibit some wave-like traits as well. Electrons, which are known and measurable quantities, also exhibit this duality. The dual nature of quanta led Werner Heisenberg to question our ability to accurately measure quanta-sized particles, which led him to the uncertainty principle. Neil Bohr further explored the dual nature of light and electrons and found that, mutually exclusive properties must also behave as complementarity.

Special Notes

1. All labs should be preceded by an in class demonstration by the teacher of the proper procedures. After viewing the demonstration, students' homework should be to prepare a plan for the experiment. Due to the time constraints of high school classes it is imperative that students have thought through the experiment before class. You, the teacher, need to know that they are aware of proper equipment set-up and safety precautions as well as appropriate hypothesis development, variable controls, and observation and measurement procedures.
2. Labs can be found in *Laboratory Manual in Conceptual Physics* by Bill Tillery.
3. Quantum physics is completely conceptual, which is good. However, it has few, if any, examples in the real world. The teacher must rely on clear lectures and lengthy discussion to achieve optimal understanding by the students.

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Unit VIII: Atomic and Nuclear Physics

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Unit VIII: Atomic and Nuclear Physics

Introduction

When people think of nuclear physics they commonly think of nuclear reactors. What we will be studying is the radioactivity of minerals in the earth's core, which power geysers, natural hot springs, and volcanoes. This unit should take about two weeks to teach. It should be divided into three sections, the atom and the quantum, atomic nucleus and radioactivity, and nuclear fission and fusion.

Intended Learning Outcomes

General Instructional Objectives (and corresponding Specific Learning Outcomes)	Unit Content
Knows terms Understands the meaning of terms	atomic nucleus, atomic number, atomic mass number, bohr model, quantized energy levels, x-, alpha, beta, and gamma rays, alpha and beta particles, nucleon, quarks, isotopes, half-life, nuclear fission and fusion, thermonuclear fusion, critical mass
Understands scientific concepts	Ritz combination principle, de Broglie matter waves, quantum mechanics, Schrodinger's wave equation, chain reaction, Correspondence principle, transmutation
Knows all laboratory procedures Prepares a plan for an experiment Participates in classroom activities Respects the scientific process Displays a scientific attitude Demonstrates skills in laboratory work	All content

Instructional Foci

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Homework, quizzes, class discussion, questions for thought from the Flying Circus of Physics

Teaching Strategies

The Bohr model of the atom should be introduced. Also atomic spectra, similar to the spectra we observed using our spectroscope, should be studied. Then the relative sizes of atoms as dictated by the electrical force from electrical charge in their nucleus should be discussed. Then the teacher should try to explain quantized energy levels based on the electron acting as a wave—a de Broglie matter wave. Then the study of quantum mechanics should be discussed, including a discussion of Schrodinger's wave equation.

To begin the section on the atomic nucleus and radioactivity, the teacher should discuss x-rays and radioactivity. Then alpha, beta, and gamma rays should be discussed. Excuse the dry nature, but then the nucleus should be studied in greater depth. The teacher should note that the nucleus is composed of nucleons, which are thought to be made of quarks that have funny names like "truth", "charm", and "beauty", and have never been isolated and experimentally observed. Isotopes are atoms that have the same number of protons, but different a different number of neutrons. The teacher can then discuss why atoms are radioactive and their half-life. When an element emits a beta or an alpha particle a different element is created. This is called a transmutation. Natural transmutations of elements should be discussed. Carbon dating is used to date everything from rocks to ancient skeletons. It is based on radioactive isotopes and their half-lives among other things. Uranium dating is also used, but it is used to date older, nonliving things. It may be useful to discuss the effects of radiation on humans.

In nuclear fission the uranium nucleus divides. Extra neutrons are liberated in the fission process, which, in turn, can cause more fission reactions in a chain reaction. Nuclear reactors and breeder reactors can then be discussed. Plutonium, which was the element in the atomic bomb, can be explored. Einstein's mass energy equivalence, $E = mc^2$, can be introduced by talking about the slightly complicated, yet pervasive throughout science laboratories, the mass spectrometer. Then the teacher can discuss fusing hydrogen isotopes together to form helium nuclei in a nuclear fusion reaction. Nuclear fusion is thought to hold the key to the future of recycling using a fusion torch, creating electrical power, and desalinating water.

Special Notes

1. Quantum physics is completely conceptual, which is good. However, it has few, if any, examples in the real world. The teacher must rely on clear lectures and lengthy discussion to achieve optimal understanding by the students.

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Unit IX: Relativity

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Unit IX: Relativity

Introduction

Einstein had a tremendous impact on modern physics. He proposed, which we know now to be true, that all measurements of space and time depend on relative motion. His special and general theories of relativity are so removed from our daily lives (since much of them are in spaceships) that understanding the concepts can be quite difficult. At this level, just becoming familiar with the concepts will be evidence of success. The unit is broken into two sections and should take a week.

Intended Learning Outcomes

General Instructional Objectives (and corresponding Specific Learning Outcomes)	Unit Content
Knows terms Understands the meaning of terms	simultaneity, time dilation, length contraction, reference frame, space-time, mass-energy equivalence, gravitational red shift, geodesic
Understands scientific concepts	Postulated of the special theory of relativity, length contraction, mass-energy equivalence, principle of equivalence
Knows all laboratory procedures Prepares a plan for an experiment Participates in classroom activities Respects the scientific process Displays a scientific attitude Demonstrates skills in laboratory work	All content

Instructional Foci

Homework, quizzes, class discussion, questions for thought from the Flying Circus of Physics

Teaching Strategies

Give it your best! Begin with a discussion of Albert Einstein and his contributions to science—

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physics in particular. Then discuss how motion is relative to your frame of reference. Discuss Einstein's postulates of the special theory of relativity, including simultaneity, space and time, and time dilation. The twin trip is a good way to approach these subjects, including length contraction. Then for the famous mass-energy equivalence, $E = mc^2$. This is the concept that everything has energy of being if it has a mass. This energy of being is called rest energy.

Underlying Einstein's general theory of relativity is the idea that gravity and acceleration cannot be distinguished from one another. Topics such as the principle of equivalence and the bending of light by gravity should be discussed. The gravitational red shift basically says that the stronger a gravitational field, the slower a clock runs. Therefore, a clock a the surface of the earth runs slower than a clock at the surface of the moon. Gravity and space should then be discussed. To conclude, a comparison of Newtonian and Einsteinian gravitation should be discussed.

Special Notes

1. Relativity is completely conceptual, which is good. However, it has few, if any, examples in the real world. The teacher must rely on clear lectures and lengthy discussion to achieve optimal understanding by the students.

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E: Course Evaluation

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Course Evaluation

Throughout the course, the teacher will assess using many sources of the students' work. The questions for thought, assigned at least weekly, will be worth one to two points each. These questions should be assigned a point value and evaluated because they encourage conceptual thinking including organizing new ideas or reorganizing old ideas. However, they should not be a large percentage of the total class grade since they are done at home so the teacher does not have control over who is actually doing the work. The weekly plan for an experiment should also be used as a procedural assessment as well as a cognitive assessment. If the specific learning outcomes have been meet, then there is evidence of main effects. The general and specific learning outcomes for the weekly plan can include the following:

General Instructional Objectives	Specific Learning Outcomes
Knows laboratory procedures	• identifies the laboratory equipment to be used • describes the steps to be followed in setting up the laboratory equipment • lists the necessary precautions in handling and setting up the laboratory equipment • describes the steps to be followed in disassembling the laboratory equipment

Prepares a plan for an experiment	• identifies the problem to be solved • formulates questions relevant to the problem • formulates hypotheses in appropriate verbal /mathematical form • describes controls for variables • formulates experimental procedures • formulates observation and measurement procedures

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	• describes the methods of data analysis • describes how the results will be presented

The weekly labs must be assessed as well. Labs—including the plan for the lab, the performance during the lab, and the lab report—are a large percentage of students' overall grade. Again, meeting the following specific learning outcomes is evidence of the main effects.

General Instructional Objectives	Specific Learning Outcomes
Demonstrates skills in laboratory work	• selects appropriate equipment for an experiment • assembles equipment correctly for an experiment • manipulates equipment as needed during the experiment • measures accurately with appropriate measuring device • follows safety rules in conducting experiment • uses materials without wasting any • completes experiment within the time limits • cleans up equipment and returns it to its proper place • manipulates data appropriately • reports results in the appropriate way • distinguishes between valid and invalid conclusions
Respects the scientific process	• favors evidence that results from scientific studies • seeks objectivity in the interpretation of evidence • changes opinions when evidence is contrary to beliefs • suspends judgement when evidence is inadequate • shows skepticism when statements are unsupported • bases ideas and opinions on the best scientific evidence available

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Displays a scientific attitude	• demonstrates curiosity in identifying problems • demonstrates open-mindedness when seeking answers • suspends judgement until all evidence is available • respects evidence from credible sources • shows willingness to revise conclusions as new evidence becomes available

In addition, multiple choice and short answer tests should be used at the end of each unit (unless it is an unusually long unit, in which case an assessment should be given in the middle and at the end of the unit) to assess whether or not students know the terms, understand the terms, and understand the scientific concepts. Use the following chart as evidence of main effects:

General Instructional Objectives	Specific Learning Outcomes
Knows terms	• identifies a definition of the term • identifies an example of the term • describes the procedure the term represents • states the concept or principle that fits the term • differentiates between the technical and the common meaning of a term
Understands the meaning of terms	• defines the term in their own words • identifies the meaning of the term when used in context • distinguished between terms that are similar in meaning • relates terms to the concepts they represent • identifies similarities and differences between terms
Understands scientific concepts	• defines the concept in their own words • identifies an example of the concept • states hypotheses based on the concept

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	• describes an experiment that illustrates the process • can list principals from which the concept was derived

Finally, there should be a small percentage of students' grades assigned to class participation. Students should be informed that the following general objectives and specific learning outcomes will be used to determine if they have earned their total class participation points.

General Instructional Objectives	Specific Learning Outcomes
Participates in classroom activities	• listens attentively • asks relevant questions • participates in classroom discussions • helps others when requested
Respects the scientific process	• favors evidence that results from scientific studies • seeks objectivity in the interpretation of evidence • changes opinions when evidence is contrary to beliefs • suspends judgement when evidence is inadequate • shows skepticism when statements are unsupported • bases ideas and opinions on the best scientific evidence available
Displays a scientific attitude	• demonstrates curiosity in identifying problems • demonstrates open-mindedness when seeking answers • suspends judgement until all evidence is available • respects evidence from credible sources • shows willingness to revise conclusions as new evidence becomes available

In addition to the intended learning outcomes, there my be some unintended learning outcomes. For example, while participating in a laboratory exercise, one or two students may end up doing all of the work for the group. The student(s) who did all of the work may feel that laboratory

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grading is unfair, while the student(s) who did no work may feel that labs are a "blow-off" and miss an integral part of the intended learning outcomes. For this reason the teacher may want to include a "question" on the lab report that asks if all the students in the group participated. Also quite unintended, but not completely unlikely, students who do not do their own work outside of class may learn that you don't have to do your own work in this world if you can hire another to do it for you. I am sure there will be other unintended learning outcomes unique to each class that should be addressed, or at least noted for future knowledge.

return to main page
return to conceptual physics curriculum
return to astromath

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F: Space Survey Researching Space

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Space Survey: Researching Space

Target Standard

Data Analysis and Probability

- Formulate questions that can be addressed with data and collect, organize and display relevant data to answer them
- Select and use appropriate statistical methods to analyze data
- Develop and evaluate inferences and predictions that are based on data

Prior Knowledge

- Graphing skills
- Data collection and interpretation strategies
- Summarizing and communication skills
- Word processing (optional)
- Electronic graphing (optional)
- Electronic presentations (optional)

Teaching Plan

Purpose

To apply survey strategies and data analysis related to space facts. Students conduct actual surveys related to knowledge of stars.

Materials

Graph paper
Post-it™ notes
Chart paper or poster board
Markers, rulers, pencils
Optional software: graphing (excel), word processor, presentation (powerpoint)

Implementation

Guided Research

1. Guide students through the research planning process using a single question. Teacher should carefully discuss the format options for posing a question (open ended or objective (a, b, c, d) options).
2. Complete the Mission together by surveying the class and following the steps of the Space Survey Research Project Report.
3. Divide students into teams and have them complete the Space Survey Research Plan and collect and record their data.
4. Teams complete their Space Survey Research Project Report.
5. Using poster board, have each team complete a draft report. Compare and contrast the various conclusions and interpretations with the class.
6. Complete the Space Survey Research Assessment.

Independent Research

1. Working in pairs, students select a research question. (See list of possible questions).
2. Teacher should carefully discuss the format options for posing a question (open ended or objective (a, b, c, d) options).
3. Together, teacher and class should set a timeline for the Mission. A posting of the deadline should be clear on all assessments and reports. By planning

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from the deadline backwards a date should be set for completion of the plan, report, and presentation.

4. Students should complete the planning sheet and turn in for teacher review. Revisions may be needed before the students are ready to begin working.
5. After completing the survey, students will need work tome to organize and analyze their data.
6. Students should draft their reports before gluing to posters or printing from computers. Teachers should assist in editing as possible. (Older children from other classrooms may be able to partner up with research teams to assist in this process.)
7. Students should complete the Space Survey Research Assessment sheet before presenting their projects.
8. Teachers assess student performances as their team presents.

Assessment

Students will design a poster or a Microsoft PowerPoint presentation of their research project. They should include all information outlined in the Space Survey Research Report. All information will be shared with an authentic audience and will be evaluated for accuracy, detail, communication skills, organization and interpretation.

Possible Research Questions:

What is the closest star? (Alpha Centauri)
How many days does it take the Earth to travel around the sun? (365¼)
What causes the seasons? (Earth's tilt)
How many constellations are in the sky? (88)
How many stars can be seen with the naked eye? (3000)
What is the brightest star? (Sirius)
What color are the stars? (White, red, yellow, and blue)
How many planets are in our solar system? (9)
Name the planets in our solar system. (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto)
What is a comet? (a dirty snowball)
Do you think there is life on other planets? (Answers will vary)
What is an asteroid? (a rock)
How old is the sun? (4.5 billion years)
What are sun spots? (an area of cooler surface temperature)
How hot is the sun's core? (15 million degrees)
What is an asterism? (a grouping of stars commonly wrongly referred to as a constellation)
Are the brightest stars the closest? (no)
What color of star is the hottest? (blue)
Why are stars different colors? (different temperatures)
Why do stars twinkle? (earth's atmosphere)
Do all planets have moons? (no)
What planets are larger than Earth? (Jupiter, Saturn, Uranus, and Neptune)
What planets have days longer than 24 hours? (Venus, Mars, Pluto)
What are stars made of? (gas, H and He)
Can you land on a star? (no)
What is a supernova? (a dying star)
What is a red giant? (a main sequence star like our sun)
What is a black hole? (a dead massive star)
What is the astronomical term for the distance light travels in a year? (a light year)
**students may generate their own questions and answers!

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Space Survey Research Project Report

Question: What was the key question you researched?

____

____

____

Materials: What materials did you use to conduct your research and complete your report?

____

____

____

____

Procedure: What steps did you take to complete your project?

____

____

____

____

Data collection: How did you gather your information?

____

____

____

Data organization: How did you clearly communicate your data?

____

____

____

____

Conclusion: What trends or patterns did you see in your data?

____

____

____

____

____

____

Implications: What did you learn from your data?

____

____

____

____

____

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Space Survey Research Project Plan

Who will you survey? ______________________________

When? ______________ Where? ______________

How will you state your question? ______________________________

____

What type of answers do you expect? (Multiple choice, open-ended, yes/no, etc.)

____

What procedure will you use to gather your information?

____
____
____
____
____
____
____
____
____
____

What materials will you need?

____
____
____

What jobs need to be done? How will you share them?

____
____
____

How do you plan on sharing your information with others?

____
____
____

What help do you need to complete this mission?

____
____
____

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Name:

Space Survey Research Project Assessment

Mission Rating Scale:
1 = Mission needs to be revised
2 = Mission in progress
3 = Mission accomplished
4 = Exceeds Mission expectations

Survey Plan: ________

Survey Report: ________
- **Question:** What was the key question you researched? ________
- **Materials:** What materials did you use to conduct your research and complete your report? ________
- **Procedure:** What steps did you take to complete your project? ________
- **Data collection:** How did you gather your information? ________
- **Graphing/Data organization:** How can you communicate your data easily? What type of graph would you include? ________
- **Conclusion:** What trends or patterns did you see in your data? ________
- **Implications:** What did you learn from your data? ________

Mission Presentation: (poster or computer) ________
- **Graphics:** ________
- **Spelling and grammar:** ________
- **Organization:** ________
- **Effective communication:** ________

Self evaluation of Space Survey Research Assessment: ________

Teamwork/cooperation: ________

Used in class time effectively to accomplish Mission: ________

Mission completed by deadline: ________

Total Score: [ ]

Comments:

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G: Voyage to Venus Mission

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Voyage to Venus Mission

Target Standard

Algebra

- Describe, extend, and make generalizations about geometric and numeric patterns
- Represent and analyze patterns and functions using words, tables, and graphs
- Model problem situations with objects and use representations such as graphs, tables, and equations to draw conclusions

Related Standard

Representation

- Create and use representations to organize, record, and communicate mathematical ideas
- Select, apply, and translate among mathematical representations to solve problems
- Use representations to model and interpret physical, social, and mathematical phenomena

Prior Knowledge

- Measurement
- Estimation to the nearest cm
- Contour maps

Teaching Plan

Purpose

To collect, organize, and analyze data to generate a model that can be used for a possible landing site on Venus.

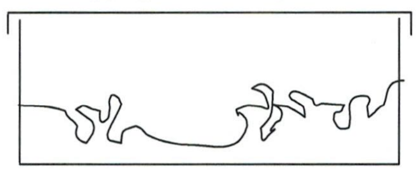
Materials

Graph paper
Skewers
Contour maps
Activity Sheet: Mission: Voyage to Venus…
To be made in advance by teacher:

- Shoe boxes with simulated Venus terrain inside them using any of the following: Newspaper, cups, rocks, tape, foil, etc…
- Play dough, using flour, salt, oil, cream of tartar, food coloring, and water (recipe provided under **Day 3**)

Background

The teacher should make the Venus boxes in advance. Begin by creating a simulation of the surface of Venus in the bottom of a shoebox using any handy materials. Be sure to create at least two flat areas for the students to choose as an appropriate landing site. For example:



Possible side view of inside of shoebox

Use graph paper or create a grid with coordinates on top of the shoebox. Punch holes with a small nail at the intersection of the grid lines for the entire surface of the box.

Implementation

Cooperative teams of two are appropriate for this activity. Students should switch between the two roles of measurer and recorder.

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Day 1

Have students use bamboo skewers to simulate radar signals bouncing off the Venusian surface. The students will poke the skewers in the pre-existing nail holes of the shoebox in a systematic way to record the elevation of the surface. Students measure and record how far the skewer goes into the box before hitting 'Venus'. *note→be sure students recognize that they are measuring the distance from the top of the box lid to the surface of Venus.*

It may be helpful to create a table as follows:

Coordinate Locations X	Y	Distance on Skewer (cm)

Day 2

Develop individual contour maps using the team data. Record data on graph paper. Discuss and develop the various view representations of their model. *For example: Aerial view and cross section.*

Day 3

Using their data, the teams re-construct a 3-D model of the Venusian terrain using Play-Dough™. The recipe for Play-Dough™ is as follows:

- 1 cup flour
- ½ cup salt
- 1 tablespoon oil
- 2 teaspoons cream of tartar
- food coloring
- 1 cup water

Mix ingredients and cook until it forms a ball and all mushy spots are gone. Knead slightly. Store in an airtight container.

Day 4

Students are given a scale model to use as one parameter for determining the landing site. Other options may be to use classroom odds and ends to create a craft of their own design fitting specified dimensional requirements. *For example: 2cm x 2cm x 2c—like gumdrops or centimeter cubes. note→ models of Venus Pathfinder Spacecraft can be made from scissors, tape, and or glue and 8.5'' by 11'' paper by downloading a small file (use the 'less sharp GIF version) from http://Venus3.jpl.nasa.gov:80/MPF/mpf/education/cutouts.html.*

Day 5

Using their models and their data (re-analyze), the teams now determine the landing sites based upon a model craft. The teams must defend their choices using their data and their models. *note→ there may be many possible sites. A set of criteria may emerge from the students interaction and teacher guidance to determine what are acceptable locations or sites.*

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Name:

Mission: Voyage to Venus Landing Proposal

Your mission: To identify a landing site on Venus for your exploring spacecraft.

Mission Landing Proposal

List landing coordinates and explain your choices below.

Choice 1:
The landing site coordinates are (________ , _______)
The surface of my first landing choice can be described as:

____
____
____
____

Choice 2:
The landing site coordinates are (________ , _______)
The surface of my second landing choice can be described as:

____
____
____
____

Why is choice 1 your top selection? Explain why you choice 1 is better than choice 2.

____
____
____
____

Proposal Presentation

Present your proposal to Mission Control. Include a map and/or model of the landscape of Venus that you investigated with two landing sites labeled. (Model spaceships may be used.)

An image of the surface of Venus from the Venera-9 mission, found at:
http://www.seds.org/nineplanets/nineplanets/venus.html

Communication 3-5

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H: Gliding through the Galaxy using Transformations

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Gliding through the Galaxy using Transformations

Target Standard
Geometry
- Apply transformations and use symmetry to analyze mathematical situations
- Analyze characteristics and properties of two-and three-dimensional geometric shapes and develop mathematical arguments about geometric relationship
- Use visualization, spatial reasoning and geometric modeling to solve problems

Related Standard
Representation
- Create and use representations to organize, record, and communicate mathematical ideas.
- Select, apply, and translate among mathematical representations to solve problems.

Teaching Plan

Part I: "S P A T I A L" Relationships: Constellation Comparisons

Purpose
Comparing and contrasting constellations based on their shapes and angles.

Materials
Transforming the Big Dipper activity sheet
Transforming the Big Dipper, The Game!
Scissors
Card stock or cardboard
Acetate
Small squares of acetate with the Big Dipper drawn on it or a transparency with multiple Big Dipper drawings on it.

Implementation
Give students a Big Dipper shape. Ask them if they recognize any patterns? How could one create a pattern? Once the pattern is identified, the students connect the stars to form the Big Dipper. *note→ discussion of constellations and origins would be appropriate here.*

Introduce transformations by having them determine how to get the Big Dipper in the various positions that represents a slide, flip and turn. You may demonstrate slide, flip, and turn with transparencies and while doing so give the students the acetate (square with a Dipper on it) and have them position the acetate into the position of the drawing in the boxes found in the **Transforming the Big Dipper** activity sheet. Write the name of the transformation type below the appropriate square. Repeat this for each image in the box. Follow this activity with **Transforming the Big Dipper, The Game!** It gives students an opportunity to sharpen their spatial abilities and enrich their geometrical terms.

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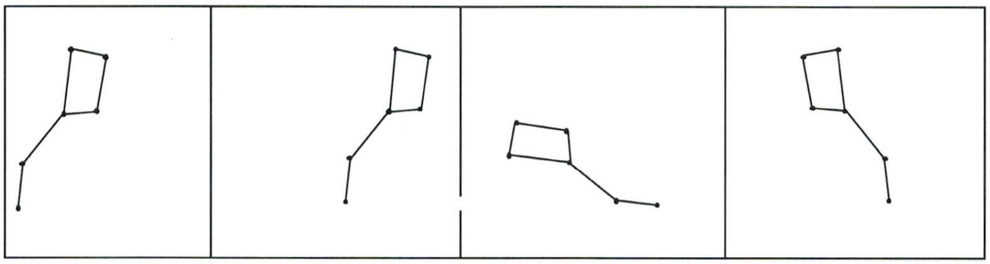
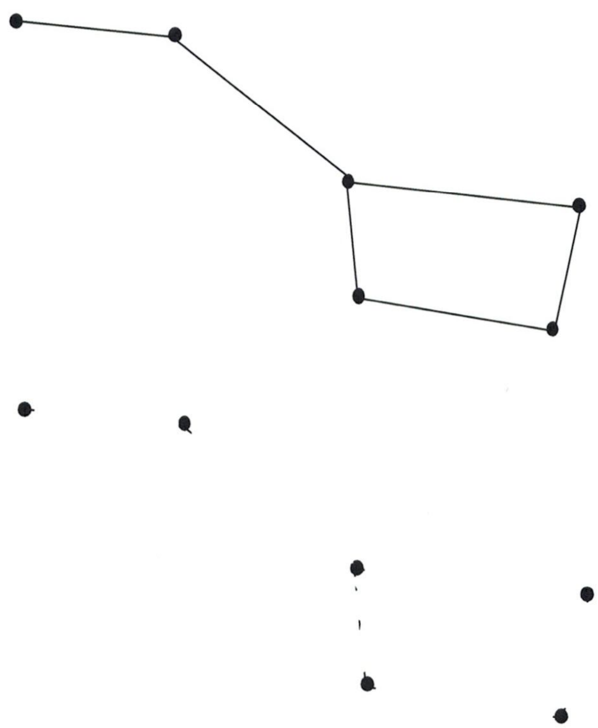
Transforming the Big Dipper



Frame 1	Frame 2	Frame 3	Frame 4
(Standard)	A.__slide______	B.__rotation__	C._flip_____

Black line master of the Big Dipper to give to students and use on overhead:



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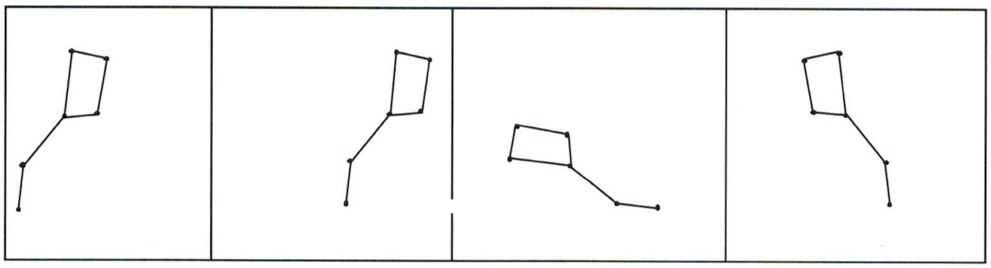
Name:

Transforming the Big Dipper



Frame 1	Frame 2	Frame 3	Frame 4
(Standard)	A.__________	B.__________	C.__________

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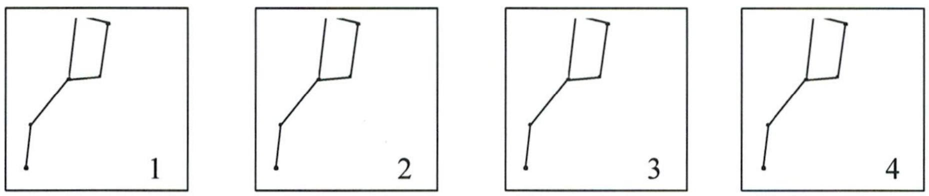
Transforming the Big Dipper, The Game!

Implementation

1. Photocopy the Big Dipper game board, rules, and playing cards.
2. On cardboard or card stock mount the game board on one side and the rules on the other.
3. Cut the playing cards apart.
4. Make a transparency of the four game pieces. The pieces should be the same size as the square on the game board and the Big Dippers should be congruent to the ones in the square (you may need to reduce or enlarge them).



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TURN (rotate)	TURN and SLIDE	FLIP and SLIDE
SLIDE (translation)	SLIDE and TURN	SLIDE and FLIP
SLIDE (translation)	TURN, SLIDE, and FLIP	TURN and SLIDE
FLIP, SLIDE, and TURN	TURN, SLIDE, and FLIP	SLIDE and TURN
FLIP, SLIDE, and TURN	SLIDE, FLIP, and TURN	SLIDE, TURN, and FLIP
TURN, FLIP, and SLIDE	SLIDE, FLIP, and TURN	SLIDE, TURN, and FLIP
TURN, FLIP, and SLIDE	TURN and FLIP	FLIP, TURN, and SLIDE
FLIP (reflection)	FLIP and TURN	FLIP, TURN, and SLIDE

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Transforming the Big Dipper, The Game! Rules

Set up:

Two, three or four people may play this game at one time.

For two players, start at spaces in opposite corners of the board.
For three players, start in any three corners.
For four players, use all four corners.

Shuffle the cards and place them in a pile face down.

Object:

The game begins with each player's transparent game piece properly positioned on the corner of the game board. The object of the game is to move the playing piece on each turn until it reaches the diagonally opposite corner of the game board an it is properly positioned on that space. This is how the game is won. On each turn, pick a card from the pile, follow the instructions, and place it face-up in a discard pile.

Moves:

A ***slide*** or translation is a motion that moves the game piece either vertical or horizontal and the distance will be one square. The Big Dipper on the playing piece must always coincide with the Big Dipper on the square.

A ***turn*** or rotation will be a quarter turn (90 degrees) in either direction. In this move, the piece will change direction, but will remain on the same game board space.

A ***flip*** or reflection will be a move that flips or reflects the game board space. Therefore, there are four possible moves.

A free space does not have a Big Dipper on that game board space. Playing pieces may land on these spaces facing in any direction. However, if a player lands on an occupied free space, the player's piece must coincide with the piece that is already there.

Moves can only take place if the Big Dippers of the game piece and the game board space look identical. Moves must be made whenever possible, even if it is considered an undesirable move. A player's chance to move is forfeiter only if it is impossible to carry out the instructions on the playing card.

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Part 2: Stellar Positions

Materials

Cassiopeia, "The Queen", Sunspot Transformation, and Cepheus, "The King" activity sheets
Acetate (if students complete the Cepheus activity sheet)

Prior Knowledge

Students must have experience with transformation of figures (slides, flips, and turns) and the associated vocabulary.

Implementation

Use the following activity sheets to give students practice with geometric transformation within the context of star positions in the night sky.

1. The activity sheet **Cassiopeia, "The Queen"**, is designed to have students identify the transformation of the constellation in the star field (more appropriate for 3rd grade). *note→ Cassiopeia in star field B is a flip from the standard, star field C is a rotation, and star field D is a slide.*
2. The activity sheet **Cepheus, "The King"**, is developed to introduce students to what telescope images do to a star image and challenge the students to draw the transformations compared to the star field standard. (This is more appropriate for upper grades). *note→ to assist the upper grade students (using the Cepheus activity sheet) in developing their spatial and geometry ability, you may wish to give them a piece of acetate and fine point marker to help them draw the transformations.*
3. Discussion of the activity sheets and the various transformations should close this part of the lesson.

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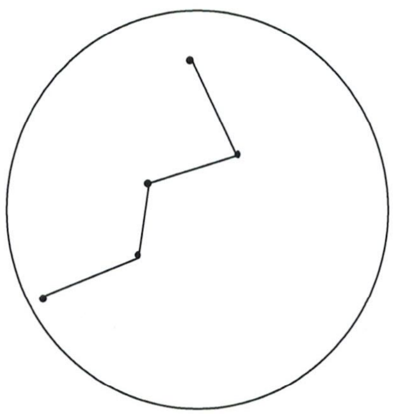
Name:

Cassiopeia, "The Queen"

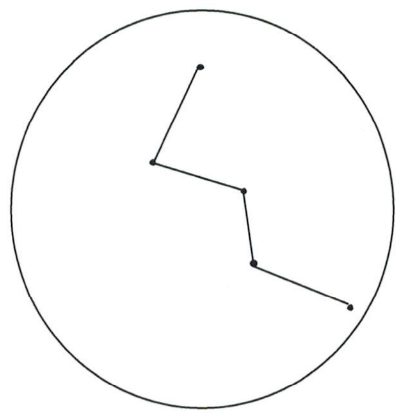
Demonstrate using transparencies that the rotation of constellations around the North Star often appears to flip constellations if you choose opposite seasons. Upon careful examination, it becomes clear that it is a rotation. In this activity you will be determining whether the constellations in the fields when compared to the criterion star field are transformed by turns, slides, or flips.

Activity Sheet: Cassiopeia

Explore the 4 star fields: Compare Star fields B, C, and D to the standard and name the type of transformation it has undergone.

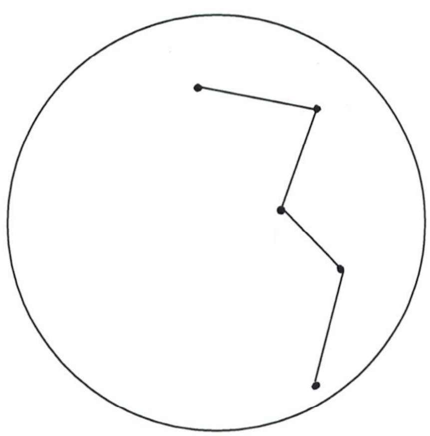


Star field A
Cassiopeia
Standard



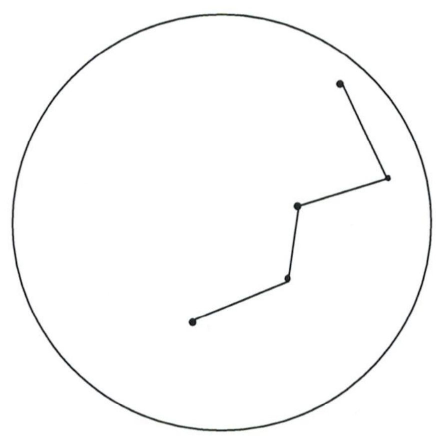
Star field B

B is ____________



Star field C

C is ____________



Star field D

D is ____________

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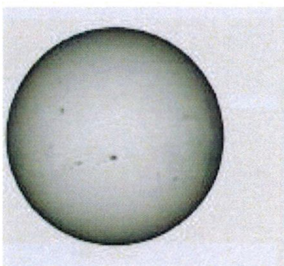
Name:

Sunspot Transformation

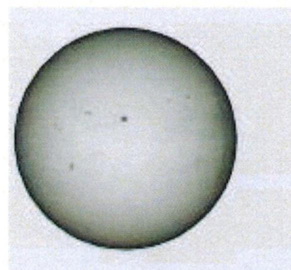
Match the Sun's picture with the view as seen from each telescope below:

Telescope 1 reflects (flips) the image
Telescope 2 rotates (turns) the image
Telescope 3 slides the image

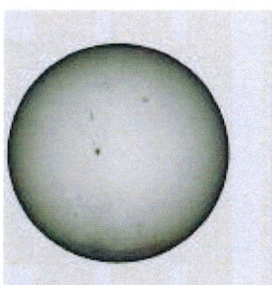
Using the sunspot pictures and the standard below, have the students identify the transformation of the solar images as taken from the telescope photos. (See the telescope key above).



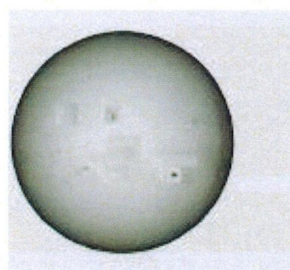
Standard sunspot image



Sunspot image 2



Sunspot image 3



Sunspot image 4

1. Sunspot image #2 came from which telescope? _______

2. Sunspot image #3 came from which telescope? _______

3. Sunspot image #4 came from which telescope? _______

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Additional Resources

http://www.thursdayclassroom.com/index_09mar00.html
http://www.thursdaysclassroom.com/index_02sep99.html
http://www.thursdaysclassroom.com/index_08june00.html
www.astro.wisc.edu/~dolan
Refracting Telescope Kit:
Learning Technologies, Inc.
40 Cameron Avenue
Somerville, MA 02144
1-800-537-8703

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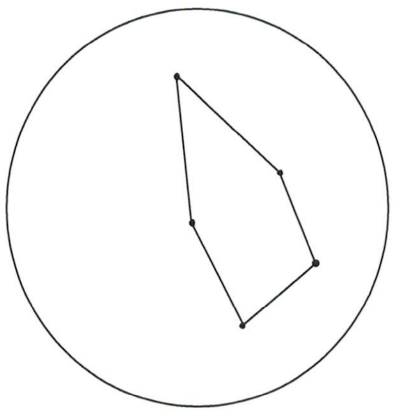
Cepheus, "The King"

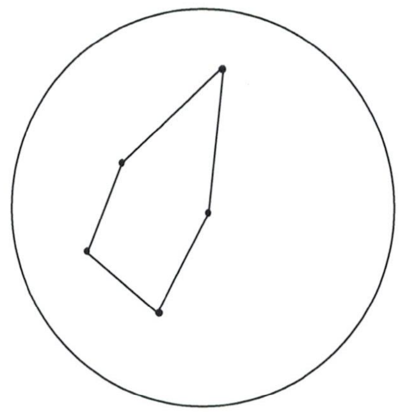
Activity Sheet: Cepheus

Using the standard star field, draw the constellation as it would look for each of the following transformations as seen when observed from the telescopes below.

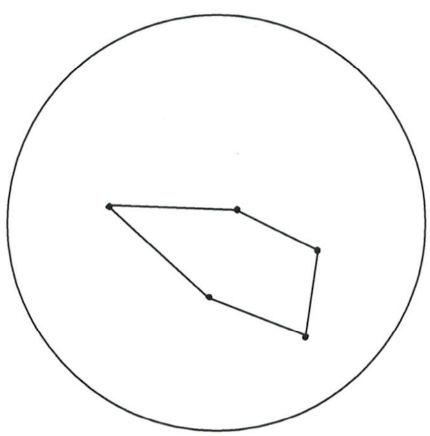
Telescope 1 reflects (flips) the image
Telescope 2 rotate (turns) the image
Telescope 3 slides the image



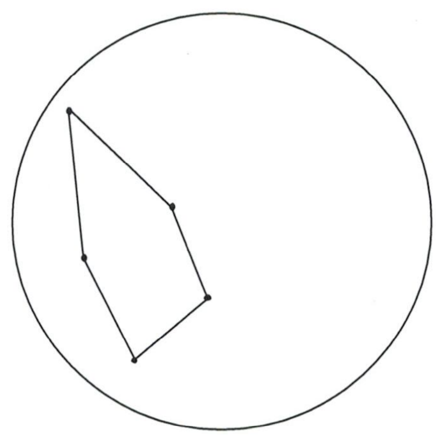
Star field A
Standard



Star field B:
Telescope 1



Star field C:
Telescope 2



Star field D:
Telescope 3

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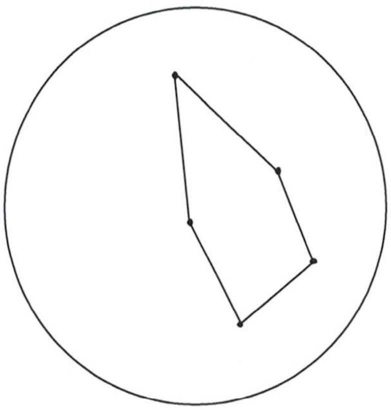
Name:

Cepheus, "The King"

Activity Sheet: Cepheus

Using the standard star field, draw the constellation as it would look for each of the following transformations as seen when observed from the telescopes below.

Telescope 1 reflects (flips) the image
Telescope 2 rotate (turns) the image
Telescope 3 slides the image



Star field A
Standard

Star field B:
Telescope 1

Star field C:
Telescope 2

Star field D:
Telescope 3

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Part 3: Do Star Positions Really Occur by Flips, Turns, and Slides?

Purpose

The purpose of this activity is to have the students determine whether changes in star positions are due to flips, turns, or slides.

Materials

Seasonal Star Maps: Summer, Fall, Winter, Spring (with the Little Dipper, Big Dipper, Cepheus, and Cassiopeia)
Stellar Seasons activity sheet

Implementation

In the previous activity with transformations, the students explored the geometric transformation within the context of constellations. Posing the question, "Do star positions really occur by flips, turns, and slides?" students explore which of these geometric transformations actually occur in nature. This should be done as a teacher demonstration with a set of transparencies using the **Star Maps** of the four seasons. note→ it is the North Star (in the Little Dipper) which does not appear to move.

1. Make a transparency of the summer constellations (**Seasonal Star Map: Summer**) that include the Big Dipper, Little Dipper, Cepheus, and Cassiopeia. Project this and identify the constellations. Discuss ways to describe the directions identified on the star map. What direction is missing? (South) Ask them what season the transparency represents? Will the same stars be seen in the winter? Will the star patterns be in the same location of the sky in the winter? Discuss their ideas and have them make predictions of what the star locations might look like in the winter. Now, place the **Seasonal Star Map: Winter** transparency over the summer transparency. Observe Cassiopeia and compare its star positions in two seasons. What geometric transformation of the constellation seems to have occurred?
2. Repeat the comparison again, looking at the Big Dipper with the spring and fall star map transparencies.
3. Previously, the opposite seasonal star maps were compared. What kinds of transformations did the discussion bring forth? Continue the lesson by sequencing the star maps in order.
   A. Project the summer star map transparency on the screen.
   B. Hand out the **Stellar Seasons** activity sheet.
   C. Have students draw the Little Dipper in the circle designated as summer on their activity sheet. Point out that the last star in the Little Dipper is known as the "North Star" or "Polaris."
   D. Point out that the North Star is the point of reference. Next, have the children draw where they think that the location of the Little Dipper will be in Fall. Repeat this for winter and spring.

   note→ Remind them to place these in reference to the standard seen in the summer transparency. Also remind them that they should be thinking of the positions in terms of slides, turns, and flips.

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E. Now, sequence the transparency sheets in order of the seasons starting with summer. Discuss the position changes and the transformation that occurred. At this point make sure to emphasize arguments for rotation or turns.
note→ The purpose is have students see that there is only one transformation that accounts for all the positions. Return to the original question, "Do these changes in star positions really occur by flips, turns, and slides?" (Rotation)

F. Have the students write a sentence using symbols, drawings, words, or diagrams to show that the positions of the stars near the North Star are geometrically transformed through "rotation" or by turns. This should lead to a discussion of what is moving, the stars or the earth? The position change of the circumpolar stars (stars that circle the North Star) during the night is due to rotation. The seasonal change of constellations is due to the revolution of the earth.

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Name:

Stellar Seasons

Summer

Fall

Winter

Spring

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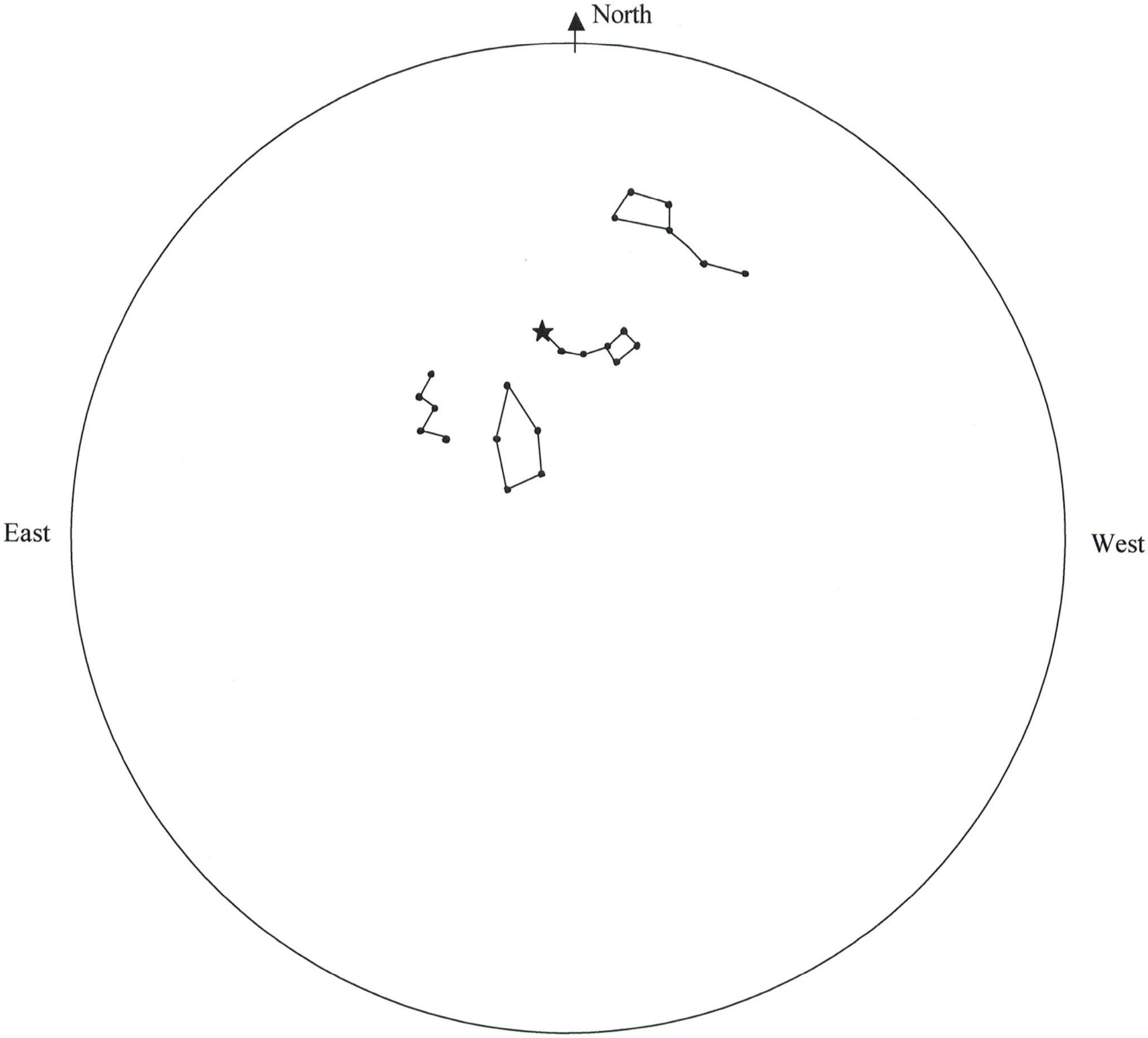
Seasonal Star Map:
Summer



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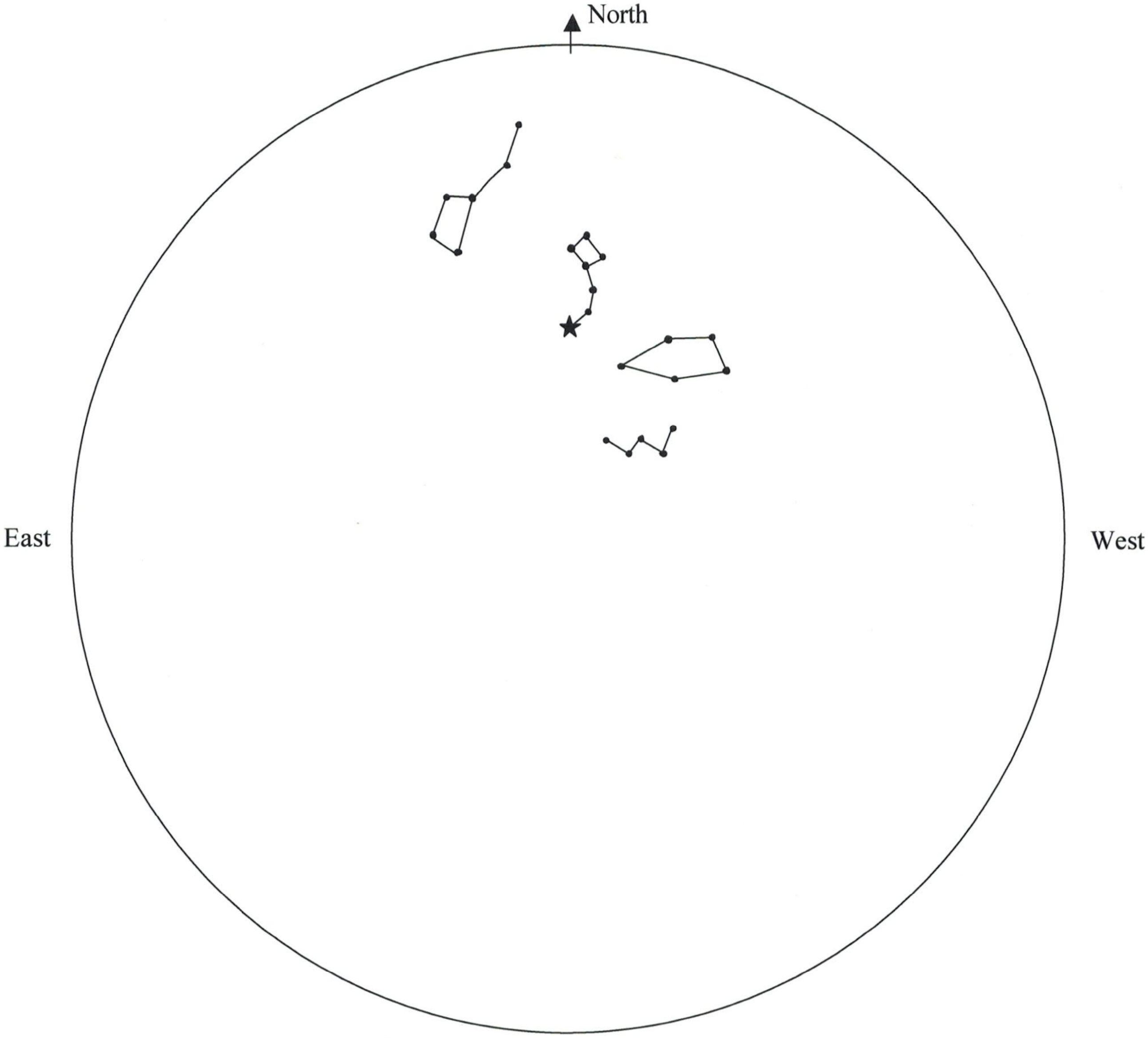
Seasonal Star Map:
Fall



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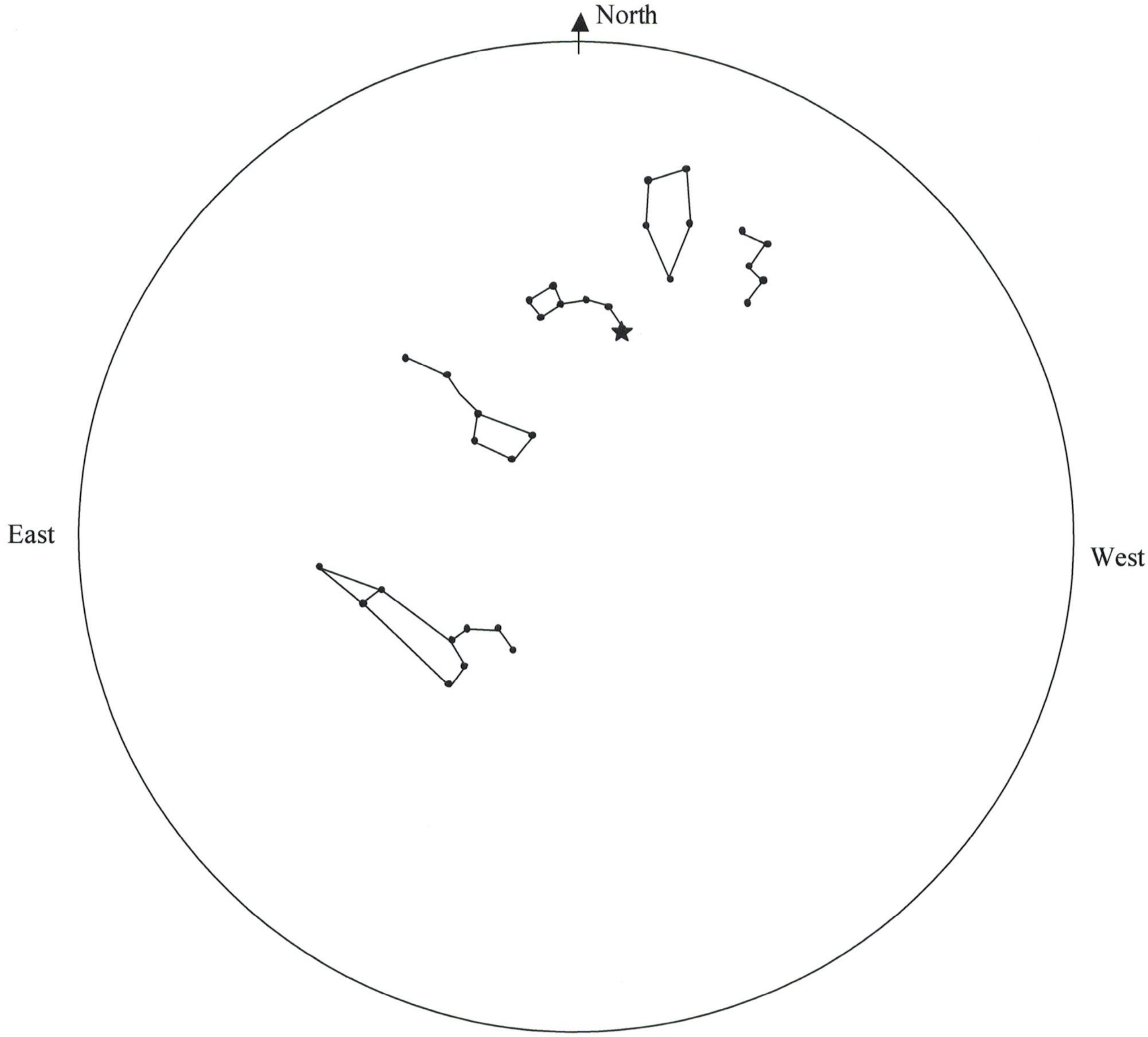
Seasonal Star Map:
Winter



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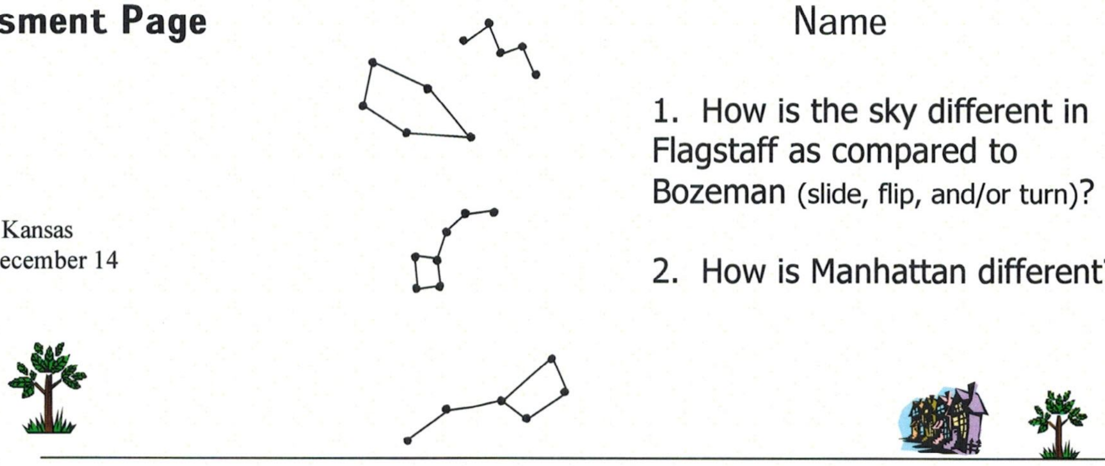
Assessment Page

Name

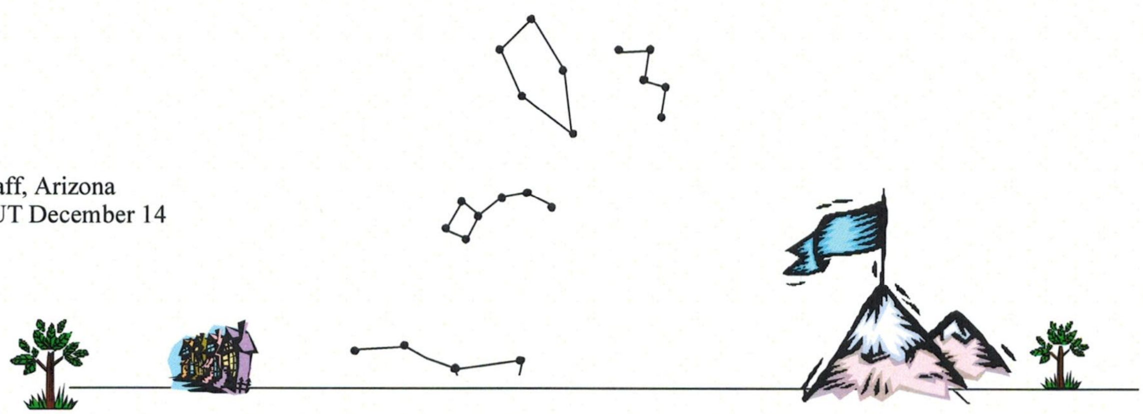
1. How is the sky different in Flagstaff as compared to Bozeman (slide, flip, and/or turn)?

2. How is Manhattan different?

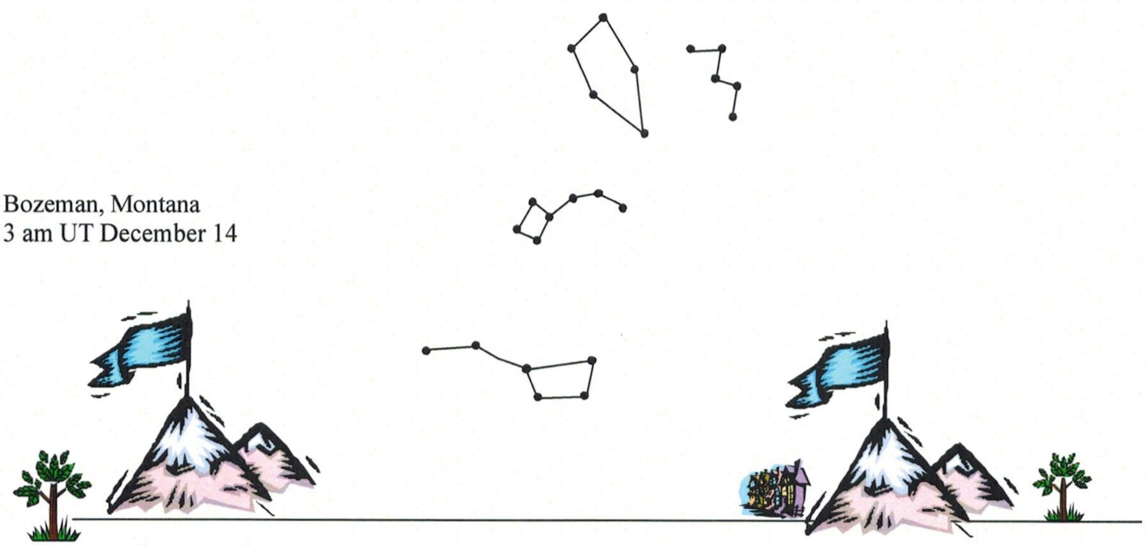
Manhattan, Kansas
3 am UT December 14



Flagstaff, Arizona
3 am UT December 14



Bozeman, Montana
3 am UT December 14



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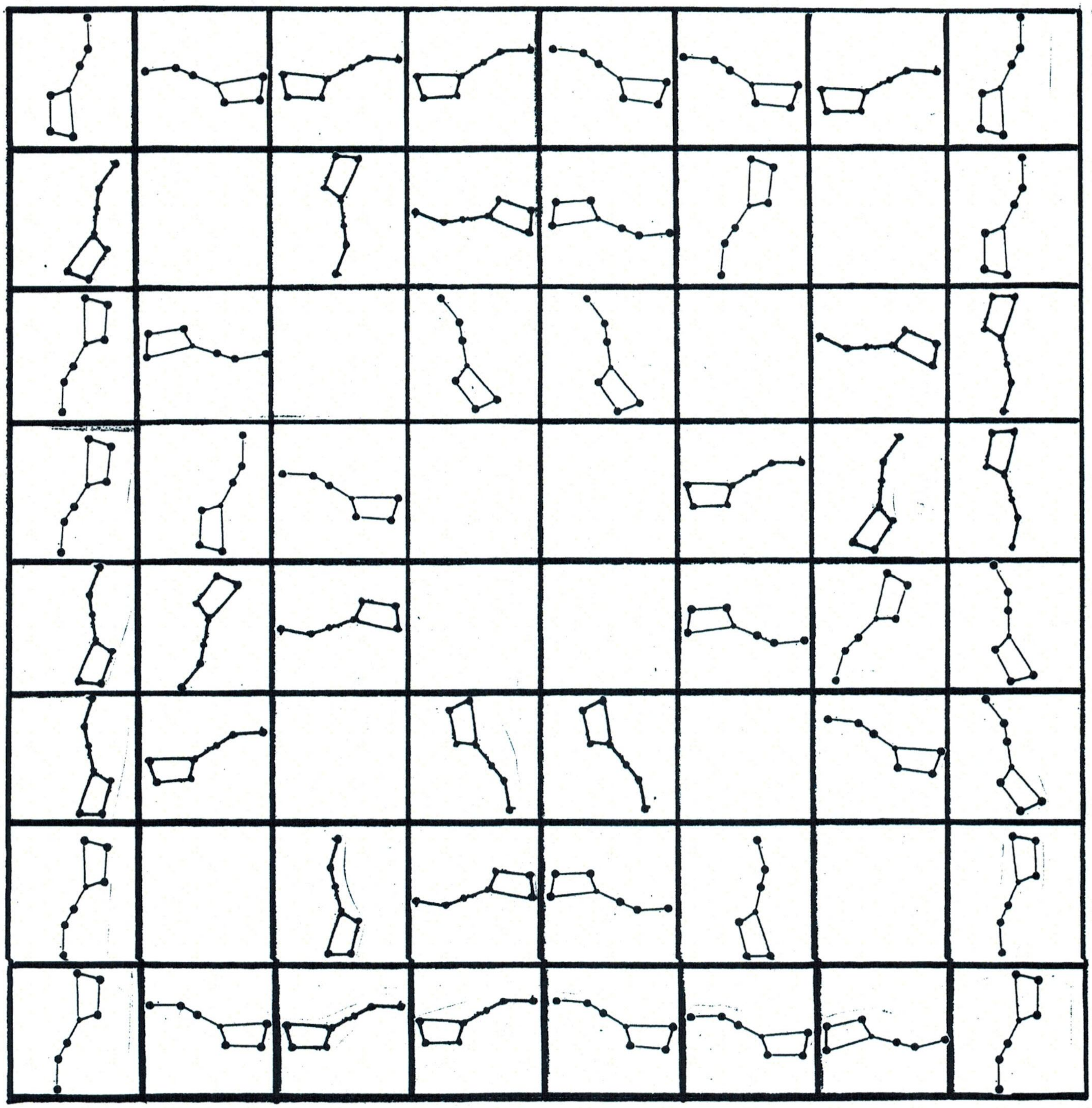
Gliding Through the Galaxy Gameboard



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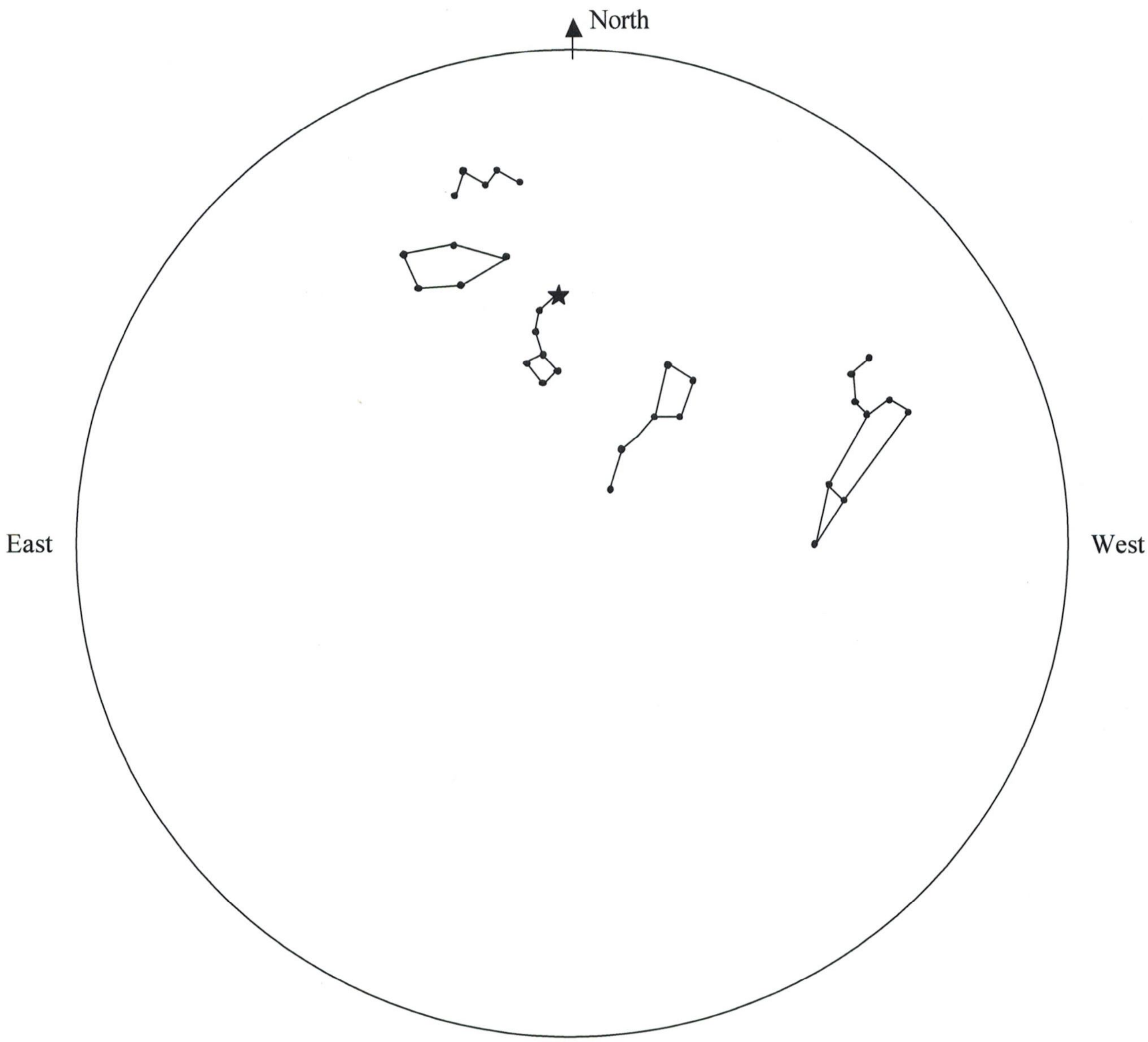
Seasonal Star Map:
Spring



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