Teaching Physical Science Through Robotics
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With the adoption of the new Georgia Performance Standards (GPS) in science, new emphasis is being placed on activity-oriented, project-based instruction and performance-based evaluation in all areas. This real-world approach to teaching science gives teachers the exciting opportunity to use new techniques to teach scientific concepts in the context in which they can be applied. One such area is robotics. The field of robotics works particularly well for the teaching of physical science concepts since:

- A robot is a system of components working together physically
- A robot is composed of components whose functions display the concepts being taught in physical science
- An understanding of scientific and engineering principals is necessary in order to design and build a functioning robot
- And, students love robots.

An examination of the Physical Science GPS at the eighth-grade shows that of the Co-Requisite Content standards, 65% can be directly taught using robotics to demonstrate the scientific concepts. The successful construction of robots and robotic components by students can be used as part of the performance evaluations to show mastery of each of these standards. In addition, 78% of the Co-Requisite Characteristics of Science standards can be taught using robotics concepts.

Low cost, high quality robot kits are available (VEX, LEGO). Several of these kits will provide nearly all the resources needed to teach Physical Science with robots. Designed to be used over and over, the components of these kits are easy for students to use and reuse in designing their robots. Both companies have resource materials available for teachers and there are a number of books written about both robot design systems. Other robot supplies are also available as off-the-shelf items.

Co-Requisite—Characteristics of Science

Habits of Mind

S8CS1. Students will explore the importance of curiosity, honesty, openness, and skepticism in science and will exhibit these traits in their own efforts to understand how the world works.

a. Understand the importance of—and keep—honest, clear, and accurate records in science. *Records need to be kept of all investigations concerning the robot, how it was designed, how*

this design meets the performance requirements for the robot, and how well things work.

b. Understand that hypotheses can be valuable even if they turn out not to be completely accurate. *The design of a robot takes much imagination and ingenuity. Many early designs (hypothesis) simply don't work, but eventually one or more are found that do.*

S8CS2. Students will use standard safety practices for all classroom laboratory and field investigations.

a. Follow correct procedures for use of scientific apparatus. *A fast moving robot can become a hazard. Correct procedures in building and handling the robot will help teach students the safe operation of scientific apparatus.*

b. Demonstrate appropriate techniques in all laboratory situations. *Weighing and measuring are important skills in the design and building of robots. The old saying, "measure twice, cut once" sums up the need for appropriate techniques in working with robots.*

c. Follow correct protocol for identifying and reporting safety problems and violations. *Because of the very real dangers associated with careless handling of robots and their parts, students will readily see the need for understanding the reporting safety problems.*

S8CS3. Students will have the computation and estimation skills necessary for analyzing data and following scientific explanations.

a. Analyze scientific data by using, interpreting, and comparing numbers in several equivalent forms, such as integers, fractions, decimals, and percents.

b. Find the mean, median, and mode and use them to analyze a set of scientific data. *Much scientific data will result from the evaluation of the performance of the various robot designs. This data must be analyzed and students will be more likely to want to evaluate the data they have collected from their robots than from other sources.*

c. Apply the metric system to scientific investigations that include metric to metric conversions (i.e., centimeters to meters). *Robots can be built in either metric or non-metric systems, but it is difficult and unnecessary, usually, to convert from one system to another.*

d. Decide what degree of precision is adequate, and round off appropriately. *There is a limit to how accurately components can be measured and cut, even though calculations of component sizes can be carried out to many more places than can be used.*

e. Address the relationship between accuracy and precision. *Without accuracy and precision, a robot will not function properly. Students readily see this as they attempt to build their robots.*

f. Use ratios and proportions, including constant rates, in appropriate problems. *Ratios and proportions are needed in the selection of*

lever, gear, pulley, and sprocket sizes based on the speed of drive and driven components, power rations, and movement ranges.

S8CS4. Students will use tools and instruments for observing, measuring, and manipulating equipment and materials in scientific activities utilizing safe laboratory procedures.—*The design and construction of robots, even if assembled from kits, require the student to develop skills in all these areas.*

a. Use appropriate technology to store and retrieve scientific information in topical, alphabetical, numerical, and keyword files, and create simple files.
b. Use appropriate tools and units for measuring objects and/or substances.
c. Learn and use standard safety practices when conducting scientific investigations.

S8CS5. Students will use the ideas of system, model, change, and scale in exploring scientific and technological matters.

a. Observe and explain how parts can be related to other parts in a system such as the role of simple machines in complex machines. *The robot is a complex system made up of simpler systems and components. Most components are simple machines used as parts of a more complex system.*
b. Understand that different models (such as physical replicas, pictures, and analogies) can be used to represent the same thing. *Robot designs can be done as drawings, mock-ups, computer simulations, CAD drawings, or as actual small working models.*

S8CS6. Students will communicate scientific ideas and activities clearly.—*Various robotic competitions (FIRST LEGO League, for instance) stress the importance of communicating information about the design of the students' robots in a scientific forum. GPS protocols require performance assessments in which students may present their work in order to demonstrate mastery of the standards.*

a. Write clear, step-by-step instructions for conducting scientific investigations, operating a piece of equipment, or following a procedure.
b. Write for scientific purposes incorporating information from a circle, bar, or line graph, data tables, diagrams, and symbols.
c. Organize scientific information in appropriate tables, charts, and graphs, and identify relationships they reveal.

S8CS7. Students will question scientific claims and arguments effectively.

a. Question claims based on vague attributions (such as “Leading doctors say...”) or on statements made by people outside the area of their particular expertise.

b. Identify the flaws of reasoning in arguments that are based on poorly designed research (e.g., facts intermingled with opinion, conclusions based on insufficient evidence).
c. Question the value of arguments based on small samples of data, biased samples, or samples for which there was no control.
d. Recognize that there may be more than one way to interpret a given set of findings.

The Nature of Science

S8CS8. Students will be familiar with the characteristics of scientific knowledge and how it is achieved.

Students will apply the following to scientific concepts:

a. When similar investigations give different results, the scientific challenge is to judge whether the differences are trivial or significant, which often requires further study. Even with similar results, scientists may wait until an investigation has been repeated many times before accepting the results as meaningful.
b. When new experimental results are inconsistent with an existing, well-established theory, scientists may pursue further experimentation to determine whether the results are flawed or the theory requires modification.
c. As prevailing theories are challenged by new information, scientific knowledge may change.

S8CS9. Students will understand the features of the process of scientific inquiry.

Students will apply the following to inquiry learning practices:

a. Investigations are conducted for different reasons, which include exploring new phenomena, confirming previous results, testing how well a theory predicts, and comparing different theories. Scientific investigations usually involve collecting evidence, reasoning, devising hypotheses, and formulating explanations to make sense of collected evidence.
b. Scientific investigations usually involve collecting evidence, reasoning, devising hypotheses, and formulating explanations to make sense of collected evidence.—*All of these features of scientific investigations can be used in the design process in order to come up with a workable robot.*
c. Scientific experiments investigate the effect of one variable on another. All other variables are kept constant.—*Each system of the robot needs to be designed by holding all variables constant while allowing one to vary. Again, this is a real world application of scientific principles demonstrated by the robot's design.*

d. Scientists often collaborate to design research. To prevent this bias, scientists conduct independent studies of the same questions.—*Students in class can be given the same design parameters yet come up with different robot designs. This replicates the same research question in different ways.*

e. Accurate record keeping, data sharing, and replication of results are essential for maintaining an investigator's credibility with other scientists and society.—*The design, testing, and redesign of a robot requires careful record keeping in order to avoid making the same mistakes over again. As students learn to build robots, they are encouraged to document the process.*

f. Scientists use technology and mathematics to enhance the process of scientific inquiry.--*A robot is a sophisticated piece of technology whose design requires the application of mathematics. There is just no way to design a robot without using math*.

g. The ethics of science require that special care must be taken and used for human subjects and animals in scientific research. Scientists must adhere to the appropriate rules and guidelines when conducting research.—*Since robots interact with humans, robot designers need to be aware of ethical issues dealing with this interaction. It is easy for students to see, for instance, that designing a powerful robot might potentially harm humans. As robots become more human-like, the ethics of robot design become more important. This concrete example is a good way to introduce the ethics of science to students*.

S8CS10 Students will enhance reading in all curriculum areas by:

a. Reading in All Curriculum Areas
- Read a minimum of 25 grade-level appropriate books per year from a variety of subject disciplines and participate in discussions related to curricular learning in all areas
- Read both informational and fictional texts in a variety of genres and modes of discourse
- Read technical texts related to various subject areas

b. Discussing books
- Discuss messages and themes from books in all subject areas.
- Respond to a variety of texts in multiple modes of discourse.
- Relate messages and themes from one subject area to messages and themes in another area.
- Evaluate the merit of texts in every subject discipline.
- Examine author's purpose in writing.
- Recognize the features of disciplinary texts.

c. Building vocabulary knowledge
- Demonstrate an understanding of contextual vocabulary in various subjects.
- Use content vocabulary in writing and speaking.

- Explore understanding of new words found in subject area texts.

d. Establishing context
- Explore life experiences related to subject area content.
- Discuss in both writing and speaking how certain words are subject area related.
- Determine strategies for finding content and contextual meaning for unknown words.

A vast amount of both fiction and non-fiction literature exists about robots. Many instructional and design manuals have been written on designing and building robots. In addition, a large body of science fiction deals with stories in which robots are an important part. Many students enjoy reading such literature and the interest generated by working with robots will lead them into further readings about robots.

Co-Requisite—Content

S8P1. Students will examine the scientific view of the nature of matter. *This is the most difficult standard to cover using robots, but it should be noted that robots are built of a variety of materials, some pure elements and some compounds, but all made up of atoms and molecules. As the robot is introduced and examined, the differences in the properties of its various components (aluminum vs. plastic) can lead into a discussion of the properties of matter.*

a. Distinguish between atoms and molecules.
b. Describe the difference between pure substances (elements and compounds) and mixtures.
c. Describe the movement of particles in solids, liquids, gases, and plasmas states.
d. Distinguish between physical and chemical properties of matter as physical (i.e., density, melting point, boiling point) or chemical (i.e., reactivity, combustibility).
e. Distinguish between changes in matter as physical (i.e., physical change) or chemical (development of a gas, formation of precipitate, and change in color).
f. Recognize that there are more than 100 elements and some have similar properties as shown on the Periodic Table of Elements.
g. Identify and demonstrate the Law of Conservation of Matter.

S8P2. Students will be familiar with the forms and transformations of energy.--*Since robots run on energy, and robotic components operate by changing one form of energy to another, this standard can be taught using robots.*

a. Explain energy transformation in terms of the Law of Conservation of Energy. Energy transformations are necessary for the robot to function. A study of any of these transformations can lead to a hands-on discussion of the Law of Conservation of Energy. *Measurements of the power dissipated by the battery and the power generated by moving components can demonstrate that it is not possible to get more energy out of the battery than is used by the robot components. In a real world, energy losses make such calculations difficult, but it us usually easy to see that you can't use more energy than what you take from the battery.*

b. Explain the relationship between potential and kinetic energy.—*This can be done by examining the robot's battery and power distribution system. Batteries contain potential energy that is stored in them. When this energy is used by a motor, it becomes kinetic energy.*

c. Compare and contrast the different forms of energy (heat, light, electricity, mechanical motion, sound) and their characteristics.—*When the robot performs its various functions, the battery's energy is converted into other forms of energy which can easily be detected and identified, for instance, light is produced by LED's and lamps, moving*

arms display mechanical motion, sound and heat are produced when the motors are run.

d. Describe how heat can be transferred through matter by the collisions of atoms (conduction) or through space (radiation). In a liquid or gas, currents will facilitate the transfer of heat (convection). *Most robots have control circuits to change speed and direction of the robot and its components. Microprocessors usually are present to give the robot commands. All of these components (and motors and lamps) generate heat which is dissipated by head sinks which conduct heat away from the robot's components and move it into the air demonstrating heat transfer through matter by conduction, convection, and radiation.*

S8P3. Students will investigate relationship between force, mass, and the motion of objects. *The robot becomes a real-world platform for investigation of the laws of motion.*

a. Determine the relationship between velocity and acceleration. *Robots accelerate when they move. Some can be programmed to accelerate in a prescribed manner. The movement of robots and their components can easily demonstrate the difference between acceleration and velocity and measurements can easily be made.*

b. Demonstrate the effect of balanced and unbalanced forces on an object in terms of gravity, inertia, and friction. *Objects move when unbalanced forces are present. It is possible to demonstrate this using individual motors on each wheel of the robot. When combinations of motors are activated, the robot's direction of motion changes.*

c. Demonstrate the effect of simple machines (lever, inclined plane, pulley, wedge, screw, and wheel and axle) on work. *Robots are built of combinations of simple machines. Not only can their function be demonstrated, but the real-world application and use of simple machines is seen in the various parts used to build the robot and make it function.*

S8P4. Students will explore the wave nature of sound and electromagnetic radiation.

a. Identify the characteristics of electromagnetic and mechanical waves.

b. Describe how the behavior of light waves is manipulated causing reflection, refraction diffraction, and absorption. *Various sensors on the robot depend on the presence and absence of light in order to function. Some robot sensors use complicated optical systems which can be investigated.*

c. Explain how the human eye sees objects and colors in terms of wavelengths. *Video cameras work in much the way a human eye works. Robots often use video cameras as sensors to detect motion or find targets. What better way to investigate vision?*

d. Describe how the behavior of waves is affected by medium (such as air, water, solids).

e. Relate the properties of sound to everyday experiences.

f. Diagram the parts of the wave and explain how the parts are affected by changes in amplitude and pitch.

S8P5. Students will recognize characteristics of gravity, electricity, and magnetism as major kinds of forces acting in nature.

a. Recognize that every object exerts gravitational force on every other object and that the force exerted depends on how much mass the objects have and how far apart they are.

b. Demonstrate the advantages and disadvantages of series and parallel circuits and how they transfer energy. *Electrical components in robots must be wired up using either series or parallel circuits. Students can gain first-hand knowledge of these circuits by building robots.*

c. Investigate and explain that electric currents and magnets can exert force on each other. *Motors are made up of permanent and electrical magnets and can be used to demonstrate that motion can come from changing magnetic fields. Solenoids and mechanical relays both operate by electromagnets and are common components on robots.*