Using Tiered Assignments to Engage Learners in Advanced Placement Physics

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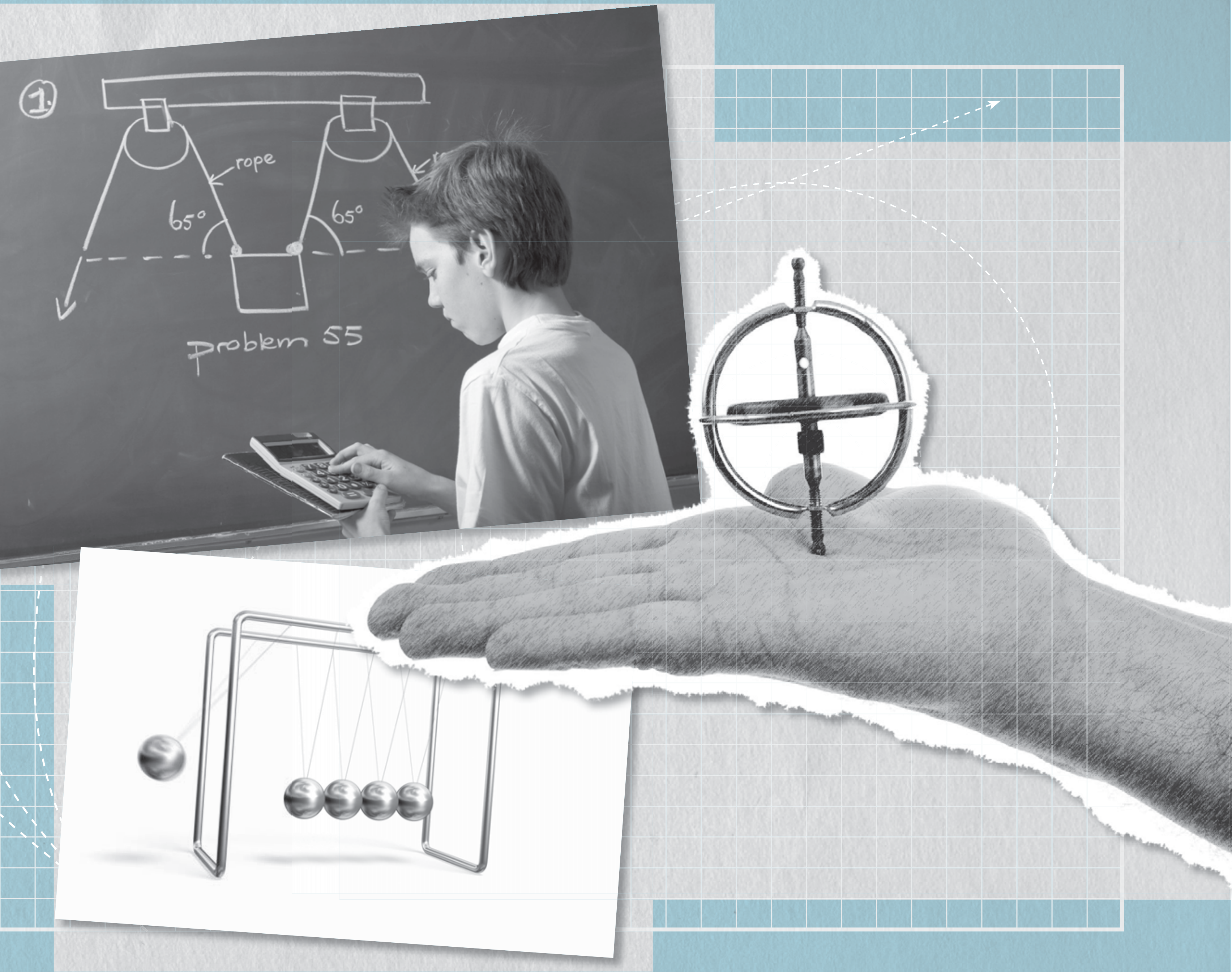
As a teacher of gifted and high-achieving Advanced Placement (AP) Physics students, I have experienced a need for publisher-provided instruction strategies and laboratory activities that are effective in engaging and motivating students in the high school setting. Because AP courses are college-level courses, most resources used in these courses are actually intended for use in a university setting and very little attention is given to differentiating instruction for the variety of students enrolled in a collegiate-level course while attending high school. When I entered the teaching profession a few years ago and was confronted with the lack of resources in this area, I relied on my previous education and experience as an engineer to develop activities based on my own work experiences. I have since refined these activities based on research in motivating and engaging gifted and high-achieving students and differentiating instruction for the varied learners in the classroom. The following lesson plans incorporate tiered objectives and brainstorming techniques as means for differentiating instruction and ensuring that learners are challenged at levels commensurate with their abilities even though they are developing an understanding of the same physics concepts (Kettler & Curliss, 2003). A listing of materials and resources supporting these activities is provided in Table 1.

The lessons require that the teacher complete an assessment of each student's learning styles, strengths, weaknesses, and interests



prior to implementation. I have used the CAPSOL learning styles inventory for this assessment (Conrath, 2005). Heilbronner (2009) recommends the Interest-A-Lyzer for determining students' interests. Students mathematical readiness must also be assessed, and I have successfully used exercises from the textbook *Is Your Math Ready for Physics?* for this purpose (Gleason, 1993). The student's current math class is another indication of the student's mathematical ability. The combination of learning styles inventories and math ability assessment is essential in placing students in learning groups (Hunt & Seney, 2005).

These lessons assume that all learners in the AP Physics class are gifted and high-achieving students but differ in mathematical readiness and learning styles; therefore, the students are divided into lab groups based on mathematical ability and learning styles. Gifted and high-achieving students are capable of abstract reasoning and higher order thinking but apply these skills in different ways that may manifest as visual, auditory, and kinesthetic learning styles. Gifted students prefer work that is student-centered rather than teacher-directed and benefit from student-to-student interaction (Hunt & Seney, 2005). The extension of these lesson plans to real-life scenarios is intended to make the lessons relevant to gifted underachievers and appeal to all ethnicities (Smink & Schargel, 2004). Also, consistent with the recommendations of the

Table 1
Materials and Resources

	Item	How to Obtain
Assessments	CAPSOL Learning Styles Inventory	http://www.stylesoflearning.com
	Interest-A-Lyzer	http://www.gifted.uconn.edu/Siegle/CurriculumCompacting/SEC-IMAG/ialsecon.pdf
	Is Your Math Ready for Physics?	Gleason, W. (1993). *Is your math ready for physics?* Dubuque, IA: William C Brown.
Lesson 1	SCAMPER template	http://www.brainstorming.co.uk/tutorials/scampertutorial.html
	Various rough surfaces such as sandpaper, plywood, and rubber matting	Hardware or home improvement stores
	Force sensor	Science lab equipment vendor, such as Vernier Software & Technology (http://www.vernier.com) or PASCO (http://www.pasco.com)
	Physics dynamics car	Science lab equipment vendor, such as Vernier Software & Technology (http://www.vernier.com) or PASCO (http://www.pasco.com)
Lesson 2	Microsoft Photo Story 3 free download	http://www.microsoft.com/windowsxp/using/digitalphotography/photostory/default.mspx
	Telescope	http://www.telescope.com or discount electronics store
	CLEA free download	http://www3.gettysburg.edu/~marschal/clea/CLEAhome.html
Lesson 3	Sample teacher website	http://www.shsphysics.weebly.com
	Sample student website	http://wearenuclear.weebly.com

ERIC Development Team on Planning Science Programs for High Ability Learners, the lessons infuse technology as a means to connect students with real-world opportunities through research, data analyses, presentations of findings, and communication with industry professionals (VanTassel-Baska, 1998).

Lesson 1: Using SCAMPER to Develop a Laboratory Exploration of Friction

This lesson incorporates brainstorming and SCAMPER to assist students in developing and implementing a laboratory experiment to observe or prove the physics principle of frictional force. SCAMPER is an acronym for substitute, combine, adapt, modify, put to other uses, eliminate, and rearrange, and is used to guide brainstorming and divergent thinking (Starko, 2005). Brainstorming allows students to creatively develop ideas for exploring the topic, and SCAMPER provides a template for evaluating these ideas to develop an effective and meaningful approach to the laboratory objective.

The lesson addresses the following College Board curriculum standards for AP Physics B:

I.B.d) Students should understand the significance of the coefficient of friction so they can:

(1) Write down the relationship between the normal and frictional forces on a surface.

(2) Analyze situations in which an object moves along a rough inclined plane or horizontal surface.

(3) Analyze under what circumstances an object will start to slip or to calculate the magnitude of the force of static friction. (College Board, 2005, p. 3)

This lesson is adapted for learners of varying ability and learning styles by developing objectives that meet the curriculum standards but allow students to achieve these standards using methods that emphasize their mathematical ability and learning styles. The students are divided into the following groups:

- *Lab Group 1* is comprised of students with the greatest mathematical ability. These students are required to empirically derive the relationship between the normal and frictional forces between an object and the surface. This task is the most mathematically challeng-

ing and abstract because students use collected data to derive a new mathematical relationship.
- *Lab Group 2* is made up of lesser mathematical ability students who prefer visual and kinesthetic approaches to learning. These students analyze the circumstances under which an object will start to slip and calculate the magnitude of the force of static friction. Group 2 students make keen and detailed observations concerning cause and effect and apply a known mathematical formula or measure force directly to determine the unknown static force.
- *Lab Group 3* hosts the least mathematical ability students who are also kinesthetic and visual learners. These students analyze situations in which an object moves along a rough inclined plane or horizontal surface. Group 3 students make keen and detailed observations and develop conceptual understanding of friction; they observe and understand mathematical relationships but do not have to derive them (Serway, 2002).

Students will require different surfaces of varying roughness such as sandpaper, plywood surface, Bakelite laboratory surface, or rubber mat. Students also need a force sensor and materials to slide across the surface such as a physics dynamics car or toy car. Each lab group is given the objective specific to the group, and the students are directed to develop a laboratory experiment to satisfy their objective. The students then brainstorm ideas for their laboratory experiment and refine their ideas using a SCAMPER template (Infinite Innovations, 2006). After students develop a consensus on the best method for conducting their investigation, they obtain teacher approval and proceed with conducting the experiment. If the students encounter difficulties during the experiment, they return to the SCAMPER template and troubleshoot their problems, modify their procedure accordingly, and proceed with the revised experiment. Students must create a poster presentation (or other product as determined by the students and teacher) of their procedure and discuss the methods used to develop the procedure, present their findings relative to the objective, and explain how their findings could ease everyday life (e.g., driving a car, moving furniture, competing for an Olympic medal in swimming).

Many teachers who have used some publishers' cookbook experiments often discover that bright students can follow the procedure and produce an answer but often do not understand how the procedure leads to the objective to be proven and don't have a conceptual understanding of the quantitative answer. Often, students find the procedures tedious and fail to read them to the degree necessary to successfully conduct the lab. By developing their own procedure, students understand firsthand how the procedure will lead to the objective and have an effective working knowledge of implementation of the procedure (VanTassel-Baska, 1998). I have observed that students require a lot of encouragement in the brainstorming phase of the activity. Lab group members are quick to judge their partner's brainstormed suggestions rather than encouraging a free flow of ideas. Students require a lot of teacher support and encouragement to gain confidence in expressing brainstormed ideas. The SCAMPER technique is then very efficient in helping students objectively reject or improve brainstormed suggestions (Cramond, 2005).

Lesson 2: Kepler's Laws of Planetary Motion Tiered Assignment

In this lesson, the students are introduced to Kepler's Laws through textbook readings and lecture-discussion, and then are given the opportunity to explore the laws further through

By developing their own procedure, students understand firsthand how the procedure will lead to the objective and have an effective working knowledge of implementation of the procedure.

group-based explorations. The applicable standards are established by College Board and are as follows:

5. Orbits of planets and satellites
   Students should understand the motion of an object in orbit under the influence of gravitational forces, so they can:
   a) For a circular orbit:
      (1) Recognize that the motion does not depend on the object's mass; describe qualitatively how the velocity, period of revolution, and centripetal acceleration depend upon the radius of the orbit; and derive expressions for the velocity and period of revolution in such an orbit.
      (2) Derive Kepler's Third Law for the case of circular orbits. (College Board, 2005, p. 9)

The explorations on Kepler's Laws of Planetary Motion are tiered in content according to readiness and tiered in product according to learning styles. Kepler's Laws are organized into three main thoughts: (a) Law of Ellipses, (b) Law of Equal Areas, and (c) Harmonic Law. The lesson applies dimensions of complexity by focusing on interdisciplinary connections with culture, religion, and mathematics (Kaplan, 2005). The activities require students to go beyond rote application of Kepler's Laws and apply methods of inquiry, investigation, and research to discover these laws through observation and analysis, consistent with Sher's (2003) urging to appreciate "the active role of the scientist is constructing meaning from observation and experimentation" (p. 206). The students then compare these findings to past and present scientific understanding. Students explore these laws by conducting research to obtain background information on Kepler and the religious and scientific beliefs of his era and gaining an understanding of the impact of Kepler's proposal. In addition, students gain a conceptual understanding of the laws by constructing models (physical or graphical) that represent planetary motion in accordance with Kepler's findings. Finally, students explore the laws quantitatively through an experiment that requires data analyses, the development of mathematical models, and drawing conclusions from those models.

The groups for this lesson are referred to as the Researchers, the Modelers, and the Analyzers. The *Researchers* review web-based and hard-copy references to gain an understanding of the scientific and religious communities' reactions to the publishing of Kepler's Laws. This group's members have not achieved the mathematical readiness to accomplish the quantitative analysis to fully explore Kepler's Laws mathematically, but possess higher order thinking skills that allow them to analyze cause and effect, gather and synthesize information, and use their findings to make predictions and judgments. These students exhibit strengths in language and interpersonal intelligence, but are weaker in mathematic ability and quantitative reasoning. The Researchers must explore dimensions of depth such as language, patterns, trends, and big ideas (Kaplan, 2005). This group gains an understanding of the relationship between religion, culture, and science, and discusses the impact of these factors on Kepler's work and on successive work. The group members continue their research to discover the impact of Kepler's work on future scientific discoveries, specifically Newton's Law of Universal Gravitation and Einstein's Theory of Relativity, and presents their findings through a bulletin board, video, or Microsoft PowerPoint or Photo Story.

The *Modelers* explore details, patterns, and trends (Isaacs, 1996). Members of this group show promise in mathematical ability and reasoning, but they have not completed the coursework necessary to successfully take on complex mathematical challenges. The members of this group work hard and are high achieving, but are on the lower end of the gifted spectrum in higher order thinking skills, and these students prefer kinesthetic learning activities. These students benefit from concrete, hands-on tasks to reinforce abstract topics. The Modelers use a telescope equipped with a measuring scale to collect moon diameter data. Because the moon's diameter appears larger when the moon is closer to the Earth and smaller when the moon is farther from the Earth, the students can use these data to construct the path of the moon's orbit. The lunar orbit may be constructed using the relationship D (distance from earth to moon) = F/d, where F is the focal length of the telescope's lens and d is the moon's diameter (Barnes, 2003). Collection of sufficient data to construct the lunar path requires one month, so teachers must plan accordingly when implementing this lesson. After obtaining the data, students plot moon diameter versus time to construct the shape of the lunar orbit. The construction may be graphical or a scale model. Students compare their findings to Kepler's First and Second Laws and present their findings in a journal that supports the model.

The *Analyzers* represent the higher end of the gifted spectrum and take on big ideas focusing on the upper end of Bloom's taxonomy: analysis, synthesis, and evaluation. The group is capable of complex abstract reasoning and has the logical-mathematical intelligence to achieve success in rigorous quantitative analyses. This group prefers the logic and efficiency of a mathematic proof and would find model-building or visual presentations tedious. The Analyzers use CLEA (Contemporary Laboratory Experiences in Astronomy) software that simulates an observatory to obtain orbital information about Jupiter's moons (Gettysburg College Department of Physics, 1997). This free, downloadable software allows students to take on the role of astronomer and view virtual images of planetary satellites. The students use the software to obtain Jupiter-to-moon distance data for each of Jupiter's four moons and determine the period of the orbits for each moon by plotting distance versus time and creating a graphical sinusoidal model of the orbital radius, R, and period, T. Then, using the period model, students determine the quantities from Kepler's Third Law that must be graphed in order to obtain a straight line whose slope will yield the mass of Jupiter, M (graphing R3 vs. T2 yields a straight line whose slope is GM/4p2, and the students solve for M). Students present their work in a formal scientific lab report.

The first time I taught Kepler's Laws, I had difficulty developing explorations because data gathering of planetary motion is time-prohibitive and limited by availability of equipment. When I received the AP exam results at the end of the school year, I discovered that this area had been the weakest area on the test for my students. It was also the only area that I had neglected to develop hands-on activities. I spent the following summer researching methodologies, laboratory investigations, available equipment, and resources for providing enrichment for Kepler's Laws. I developed a laboratory investigation similar to the activity described for the Analyzers. A small percentage of the students were completely successful with this activity and thoroughly enjoyed it. Others found it tedious, and still others were completely defeated by it. The most successful students were those with the greatest mathematical ability and logical-spatial intelligence. I developed the Researchers and the Modelers activities to provide enrichment for those students who are highly capable but have not advanced through mathematics at the same rate as the Analyzers. Implementing this tiered lesson resulted in improved performance on this area of the AP exam.

Lesson 3: Using Problem-Based Learning to Explore the Application of Nuclear Technology to Alternative Energy Development

This lesson synthesizes a problem-based learning strategy with tiered objectives to explore the application of nuclear energy to address the need for alternative energy sources. This lesson is suitable for students in AP Physics B or honors physics courses and addresses the following College Board AP Physics B standards:

V. Atomic and Nuclear Physics
  B. Nuclear Physics
    a) Students should understand the significance of the mass number and charge of nuclei, so they can:
      (1) Interpret symbols for nuclei that indicate these quantities.
      (2) Use conservation of mass number and charge to complete nuclear reactions.

Figure 1. Sample student website home page.

(3) Determine the mass number and charge of a nucleus after it has undergone specified decay processes.

b) Students should know the nature of the nuclear force, so they can compare its strength and range with those of the electromagnetic force.

c) Students should understand nuclear fission, so they can describe a typical neutron-induced fission and explain why a chain reaction is possible. (College Board, 2005, p. 20)

This lesson goes beyond the AP Physics B core standards for atomic and nuclear physics, and some teachers may find the lesson well suited as an enrichment or culminating year-end activity. In this lesson, students take on the professional roles of nuclear engineer, environmental engineer, politician (state legislative representative), and energy consultant, and must perform research, analyze findings, and synthesize data to develop a risk-benefit analysis of a new nuclear power facility in their community. The risk-benefit analysis and a recommendation are published via a student-generated website (see Figure 1).

According to Gallagher (2005), a well-structured problem-based learning activity must combine an "ill-structured problem, the student as stakeholder, the self-directed learner, and the teacher as coach," and this lesson attempts to create a learning environment consistent with these requirements (p. 289).

The students are presented with the following scenario that can be modified by the teacher to reflect the characteristics of the students' community:

> The climate change crisis and rising energy costs have all Americans questioning the wisdom of our dependence on oil. Energy costs, along with current mortgage lending practices and other factors, have contributed to a declining economy and the need for job creation.
>
> Population growth in the Atlanta metropolitan area and the entire Southeast, along with continued and unprecedented energy consumption, has created the need for additional sources of energy production for this geographic region. Southern Energy has proposed the construction of a new nuclear power facility on Lake Alatoona in Cherokee County as a way of addressing increasing energy demands and creating jobs in an ever-declining economy. The citizens of Cherokee County are excited about the possibility of new jobs but concerned about the perceived dangers of nuclear power and the adverse environmental impact created by construction near Lake Alatoona. The Cherokee County Commissioners will convene in one week to discuss the proposal and vote for or against moving forward with petitioning the Nuclear Regulatory Commission for permission to build a power plant in the community.
>
> The Cherokee County Commissioners have assembled a team of experts to investigate and develop a risk-benefit analysis and recommendation concerning the construction of the nuclear power facility. The team's findings will be published on the county website for community members to view and provide feedback. The team includes a nuclear engineer, the Cherokee Country district representative, an alternative energy consultant, and an environmental engineer. The goal of the team is to perform the necessary research and work together to create the community website to educate the citizens prior to the town meeting.

The students are assigned roles based on their mathematical ability and learning styles (with ability taking first priority). Each team has a nuclear engineer, environmental engineer, politician, and alternative energy consultant. The nuclear engineers have had some prior experience with physics and are well advanced in the school's math curriculum (they are coenrolled in precalculus or calculus). These students are capable of complex abstract reasoning and have the logical-mathematical intelligence to achieve success in the rigorous quantitative analyses required to analyze the nuclear physics concepts involved in this activity. The environmental engineers have not achieved the mathematical readiness to accomplish the quantitative analysis required by the nuclear engineers, but possess higher order thinking skills that allow them to analyze cause and effect, gather and synthesize information, and use their findings to make predictions and judgments about environmental impact. The politicians explore the impact on the public image of the county if the nuclear facility is constructed. These students exhibit strengths in language and interpersonal intelligence, but may be weaker in mathematical ability and quantitative reasoning. Their creativity and attention to aesthetics will prove a benefit to the development of the website. The alternative energy consultants show promise in mathematical ability and reasoning, but they have not completed the coursework necessary to successfully take on complex mathematical challenges. This group works hard and is high achieving and will research alternative energy solutions based on qualitative rather than quantitative analyses.

All students require access to reference materials to research their assigned topics. The lesson should be conducted in the school media center or in a classroom with computer access. Students may choose to interview local professionals to obtain data and will require access to telephones or e-mail. Students will also require website development software or use of a web-based utility such as http://www.weebly.com or http://www.wikispaces.com.

To begin the lesson, the teacher organizes the students into teams as previously described and presents the scenario to the class via a simulated letter written to the team of student role-players. After receiving the simulated correspondence from the county commissioners, the teacher presents the team members with cards that define their roles and provide specific questions that guide the students in developing their portion of the analysis (instead of cards, I present the information via a website that I created for this purpose, http://shsphysics.weebly.com).

Job descriptions and tasks are provided below.

- *Nuclear Engineer*. The nuclear engineer is responsible for researching the operation of a nuclear power plant. After understanding how the plant operates, the engineer develops a summary of the benefits and hazards of constructing and operating a nuclear power plant in our county. The nuclear engineer must provide the following information to the team: (a) definition of fission and how it is accomplished; (b) explanation of the operation of a nuclear power plant; (c) discussion of the design of a nuclear power plant; and (d) explanation of the safety measures taken to protect against accidents.
- *State Legislative Representative.* The state representative is responsible for educating the community on the job opportunities and economic stimuli provided by the proposed nuclear power plant. The representative also has to research and report on policies related to nuclear power for the state and provide the following information: (a) nuclear power benefits, if any, to the state; (b) discussion of the state and national regulations concerning nuclear power and safety; (c) job opportunities provided by the plant; (d) community improvements, if any, provided by the plant; (e) statistics for the support or opposition to nuclear power plants in the state; and (f) other economic benefits provided by the plant to the community.
- *Alternative Energy Consultant.* The energy consultant is responsible for educating the community on the use of nuclear power for electricity production compared to other energy choices. The energy consultant is required to provide the following information: (a) relative benefits, if any, to alternative forms of electricity production; (b) cost of nuclear power plant construction and operation compared to the cost of alternative energy sources; (c) fissile fuel costs compared to alternative fuel costs, (d) waste storage costs and impact; and (e) emergency actions and considerations in the event of a nuclear accident requiring an evacuation.
- *Environmental Engineer.* The environmental engineer is responsible for educating the community on the environmental impact of constructing and operating a nuclear power plant on the community lake. The environmental engineer should investigate and provide information on the following: (a) potential pollutants associated with nuclear power plants; (b) impact on the lake and tributaries; (c) potential hazards to those living near the plant; (d) potential hazards to plant workers; (e) environmental impact of construction of the plant; and (f) waste disposal environmental considerations.

After the students have read the cards and understand their roles, they may regroup by professional type (i.e., the nuclear engineers work together, alternative energy consultants work together, etc.) to perform the research for their areas. After the data are gathered, the original teams of various professionals reconvene to assemble their findings into a risk-benefit analysis. The students then work together to develop a website documenting their findings and persuading the public of their position on the construction of the nuclear power facility.

The lesson offers a real-world scenario with a product that is published on the Internet. The product, a website, is the same for all students; however, the students must choose how to convey information via the website. Because the target audience is the citizens of the community, the students must judge the best method of developing the website (e.g., information to include, layout, interactive features, animations) to persuade the public of their recommendation. The multifaceted nature of the lesson allows for the teaching of multiple standards in one unit of study. Additionally, the lesson could be divided into disciplines such as environmental science, social studies, and physics and incorporate a multicurriculum approach with social studies classes researching the role of the public official, environmental science students taking on responsibility for the environmental impact research, and physics classes pursuing the nuclear physics tasks. My students consistently report that this lesson is one of the most enjoyable, meaningful, and engaging academic experiences of the course.

All of these lessons attempt to meet the needs of gifted learners in science classrooms with the understanding that even within the gifted population, differentiation of content, process, and product is required to meet the diverse needs of accelerated learners (Kaplan, 2005). The lessons emphasize higher order thinking skills, incorporate problem-based learning, utilize technology, and emphasize experimental design and scientific process as recommended by VanTassel-Baska (1998). Even though students are developing an understanding of the same physics concepts, the process is differentiated through tiered objectives for students that allow them to rely on their unique strengths to achieve the curriculum goals. Even though these lessons are specific to the secondary physics classrooms, the strategy of tiered objectives may be generalized to other courses and teaching situations by assessing students' strengths and interests and developing group activities that capitalize on those assessments and allow for student self-direction and problem-based learning. **GCT**

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