Playing Physics Jeopardy

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Citation: American Journal of Physics **67**, 252 (1999); doi: 10.1119/1.19233
View online: https://doi.org/10.1119/1.19233
View Table of Contents: https://aapt.scitation.org/toc/ajp/67/3
Published by the American Association of Physics Teachers

Playing Physics Jeopardy

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(Received 29 December 1997; accepted 22 July 1998)

This article presents a new format for physics problems that is similar to the game show Jeopardy in which contestants are given the answer to a question and asked to state the question. In Physics Jeopardy, the problem starts with a mathematical equation, a graph or a diagram that describes a physical process. The solver constructs other representations of the problem including a word or picture description of a problem and process that is consistent with the equation, graph, or diagram. The Jeopardy Problem solution becomes an effort to represent a physical process in a variety of ways—sketches, diagrams, graphs, and equations—more like the method used by experienced physicists when analyzing problems. © *1999 American Association of Physics Teachers.*

I. INTRODUCTION

Richard Feynman's last blackboard contained the words: ''Given *S* matrix, find problem.'' Feynman's suggestion can be adapted nicely for physics instruction at all levels. Students are given an equation that describes a physical process. They then work backwards to construct diagrammatic, graphical, pictorial, and/or word descriptions of a process that is consistent with the equation. There may be many appropriate processes for a particular equation. We call this Physics Jeopardy after the television game show in which contestants are given the answer to a question and are asked to think of the question for that answer. In another version of Physics Jeopardy, students are given a graphical or diagrammatic description of a process. They then construct other representations of the process, including a word description and a description in the form of an equation. An interesting idea perhaps, but why should we do this?

For many years physics instructors believed that the ability to solve problems was an indication that students had mastered the concepts and principles. After all, solving these problems required the application of the concepts and principles to new situations, and that seemed possible only if someone really understood the ideas. However, research over the past twenty years has demonstrated clearly that students can learn to solve numerical problems with a minimal conceptual foundation.[1–4]

New qualitative approaches to improve learning have evolved from this research on conceptual understanding. But problem solving remains a critical aspect of physics. Do end-of-chapter problems help? Sweller and his colleagues argue in a series of articles[5–7] that traditional physics problems may actually be counterproductive for helping students learn the concepts. Larkin *et al.*[8] emphasize that many novice students use a general problem technique called means-ends analysis when solving standard problems. Sweller and his colleagues indicate that a means-ends analysis approach focuses the solver's attention on the mathematical representation, i.e., the equations and not on the conceptual aspects of the situation. Means-ends analysis requires a significant portion of the solver's cognitive resources, leaving few resources to use for conceptual learning. So the question remains: How do we help students develop qualitative understanding while at the same time helping them learn to use the symbolic language of physics with understanding?

A multiple representation process helps. Howard Gardner said:[9] ''Genuine understanding is most likely to emerge, and be apparent to others, if people possess a number of ways of representing knowledge of a concept or skill and can move readily back and forth among these forms of knowledge.'' Larkin[10] described a sequence of representations that an experienced physicist uses to solve physics problems. The process starts with a word description. A pictorial description of the process follows with a crude sketch of everyday objects in realistic physical settings. Next comes a physical representation, which is often a diagram or graph that involves physical quantities. The physical representation is then converted to the mathematical representation which is the application of a basic principle to the process. Finally, a numerical answer is obtained. There is continual evaluation of the different representations for self-consistency and reasonableness.

Van Heuvelen[11] suggested that Jeopardy Problems starting with equations and then leading to a word description of a process would require deeper conceptual understanding of the symbolic language of physics—like reading a classic. Earlier, Maloney[12] suggested that students' understanding of the concept of force might improve if students interpreted a process described by a force diagram. In the remainder of this paper we will provide several examples of Jeopardy Problems and will examine the strengths and weaknesses of this format.

II. EQUATION JEOPARDY PROBLEMS

In Equation Jeopardy, you reverse the normal process by providing a mathematical equation as the given information and asking the student to construct an appropriate physical situation that is consistent with the equation. Consider a simple example,

$$N-(60\ \mathrm{kg})(9.8\ \mathrm{m/s^2})=0.$$

This could be a 60-kg object, perhaps a person, standing on a surface [Fig. 1(a)]. A less obvious choice is a 60-kg person sliding on a horizontal, frictionless surface [Fig. 1(b)]. Students will most likely make some version of the first choice. A professor might ask them if the second choice is also

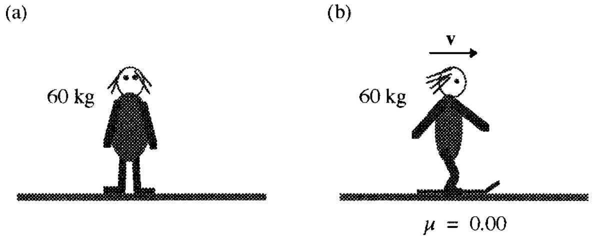

Fig. 1. The equation $N-(60\ \mathrm{kg})(9.8\ \mathrm{m/s^2})=0$ describes the situations shown in (a) and (b).

appropriate—an opportunity to confront a common student alternative belief.

The first example is quite simple. More challenging Jeopardy Problems can be created with relative ease. Take a standard problem and use a basic principle to write an equation that describes the problem process. Consider the following examples that represent either the description of a process at one instant of time or a continuous process with a beginning and an end (the initial and final states of the process). An example of the latter is shown below with the left side of the equation representing the initial state and the right side the final state,

$$1/2(6000\ \mathrm{N/m})(2.00\ \mathrm{m})^2=(72\ \mathrm{kg})(9.8\ \mathrm{m/s^2})(17\ \mathrm{m}).$$

The 1/2 times a number with units N/m times the square of a distance causes an experienced physicist to think of the elastic potential energy of a stretched or compressed spring. On the right side of the equation we have gravitational potential energy with a mass, the acceleration due to gravity and a distance (height). If the left side is the initial energy and the right side the final energy, the process might involve an ejector seat with a compressed spring launching a 72-kg object (another person) upward a maximum distance of 17 m. There could of course be other processes described by the equation, such as a compressed spring launching the object up a frictionless incline so that the total change in elevation is 17 m. Students are encouraged to think divergently when inventing processes described by the equations.

A Jeopardy Problem representing a steady state process is shown below:

$$12\ \mathrm{V}=I\{[1/(5\ \Omega+6\ \Omega)+1/(8\ \Omega)]^{-1}+14\ \Omega]\}.$$

The task here is to draw an electric circuit. Once again the student must translate a mathematical relation into a reasonable physical situation—in this case a diagram rather than a verbal statement.

Consider a Jeopardy Problem that is followed by a series of questions to help students develop better conceptual understanding,

$$-(1.39\ \mathrm{kg})(9.8\ \mathrm{m/s^2})$$
$$+(780\ \mathrm{kg/m^3})(9.8\ \mathrm{m/s^2})(1.78\times10^{-3}\ \mathrm{m^3})=0.$$

After students decide that the equation describes an object floating in some liquid, which is not water, we might ask additional questions. What is the liquid? What is the volume of the floating object in liters? This latter question requires the student to realize that the $1.78\times10^{-3}\ \mathrm{m^3}$ in the right term of the equation is a lower limit for the volume of the object. The object would be in neutral buoyancy if immersed to its full volume and still ''floating.'' Since the $1.78\times10^{-3}\ \mathrm{m^3}$ is the lower limit for the object's volume, the volume must be $1.78\times10^{-3}\ \mathrm{m^3}$ or greater. The student must also think about units and conversions because the volume is given in the equation in $\mathrm{m^3}$, but the question asks for the volume in liters.

Consider a Jeopardy Problem involving the component form of Newton's second law applied to an object on an incline,

$$150\ \mathrm{N}-(14.5\ \mathrm{kg})(9.8\ \mathrm{m/s^2})\sin 34^\circ-(0.32)(14.5\ \mathrm{kg})$$
$$\times(9.8\ \mathrm{m/s^2})\cos 34^\circ=(14.5\ \mathrm{kg})a_x.$$

With a little work, a physicist will recognize that something exerts a 150-N force parallel to a 34° incline while pulling (or pushing) a 14.5-kg object up the incline. There is friction with a 0.32 kinetic friction coefficient between the object and the inclined surface. This Jeopardy Problem is somewhat more challenging. We can ask the students to translate from the mathematical representation to a physics sketch, a free-body diagram in this case, and then from the diagram to a picture-like sketch of an appropriate physical situation. Finally, students could be asked to invent a word problem that is consistent with the equation.

Jeopardy Problems can be constructed for all physics subjects. For example, students might be given an application of the first law of thermodynamics ($Q=\Delta U+W$) for an ideal gas, where W is the work done by the system:

$$Q=(8.0\ \mathrm{mol})(8.31\ \mathrm{J/mol\,K})(361\ \mathrm{K})\ln(34.3\ \mathrm{L}/60\ \mathrm{L}).$$

The students would either be asked to describe a physical process for which the equation applies or to answer a variety of questions such as the following. What type of process is this? How do you know? What are the volumes and pressures for the initial and final states of the process? What actually happened to the gas during the process? Did the gas do work during the process? Explain. By how much did the internal energy of the gas change during the process? Was there heat transfer to or from the gas?

As another example, we might ask students to draw a sketch that represents a process described by the following equation (suggested by F. Munley):

$$1.5\times10^{-6}\ \mathrm{N}=(1.0\times10^{-5}\ \mathrm{C})v(0.010\ \mathrm{T})0.50.$$

This could be the magnetic force exerted on a charged object moving at 30 m/s relative to a magnetic field. Why the 0.50 at the end of the equation? The student needs to consider the relative directions of the magnetic field and the velocity.

A more complex problem provides the coupled equations that result from the application of Newton's law to a system of objects connected together by ropes and moving as one. Consider the equations below:

$$T_1-(0.15)(28\ \mathrm{kg})(9.8\ \mathrm{m/s^2})=(28\ \mathrm{kg})a_x,$$
$$T_2-T_1-(0.15)(71\ \mathrm{kg})(9.8\ \mathrm{m/s^2})=(71\ \mathrm{kg})a_x,$$
$$T_3-T_2-(0.15)(48\ \mathrm{kg})(9.8\ \mathrm{m/s^2})=(48\ \mathrm{kg})a_x.$$

Similar multiple-equation problems can be constructed for many other physics concepts: systems of static electric charges; systems in static equilibrium; the application of Kirchhoff's rules to an electric circuit; kinematics equations for multiobject systems (a truck passing a car at a stop sign) or a multipart single-object problem with different accelerations in each part (for example, a bottle rocket's vertical flight).

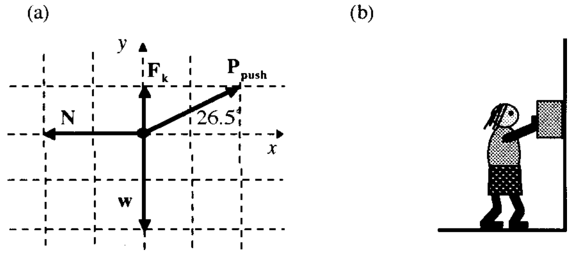

Fig. 2. The free-body diagram shown in (a) represents the process shown in (b).

III. DIAGRAM AND GRAPH JEOPARDY PROBLEMS

In Diagrammatic and Graphical Jeopardy Problems, students are first given a diagram or graph. They then invent a word or picture description and a math description for a process that is consistent with the diagram or graph. Consider the force diagram in Fig. 2(a). Tell as much about the situation as you can.

The force diagram could describe a box or block moving downward at constant velocity along a vertical wall [Fig. 2(b)]. The normal force indicates that the object is pressed against a vertical wall. The kinetic friction force indicates that the object is moving down. Notice that the y components of the forces parallel to the wall's surface add to zero. This provides a nice opportunity to confront the common belief (misconception) that there must be a net force in the direction of motion in order for that motion to continue.

In another problem, students are given a position-versus-time graph (Fig. 3). They then construct a motion diagram, a velocity-versus-time graph, and an acceleration-versus-time graph—all consistent with the position-versus-time graph. Finally, they invent a process that is consistent with all of these descriptions. Other types of Jeopardy Problems can start with a graph. For example, we might provide a graph of magnetic flux-versus-time or of the electric potential energy of a particle in an electric field as a function of time.

Energy bar charts lend themselves nicely to this type of Jeopardy Problems. The bar chart shown in Fig. 4 indicates that the system starts with considerable elastic energy (U_s) and ends with kinetic energy (K) and gravitational potential energy (U_g). One possible process would be a compressed spring that launches an object up an incline or straight up into the air. The object has some speed and kinetic energy at the final state of the process. Students must understand the meaning of the different types of energy in order to invent a process that is consistent with the bar chart.

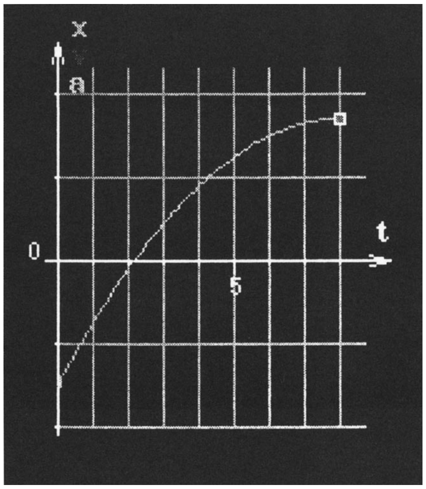

Fig. 3. Invent a process that is consistent with the kinematic position-vs-time graph.

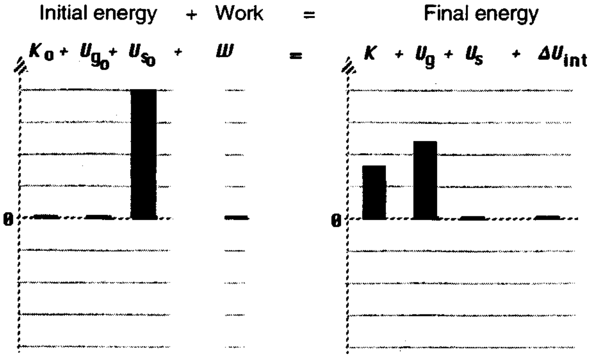

Fig. 4. A qualitative work-energy bar chart—what's the process?

IV. SIMULATION JEOPARDY PROBLEMS

All of these types of Jeopardy Problems can be used with simulations. For an Equation Jeopardy Problem, the student is first given an equation that describes a physical process. After students invent their own process, they can be shown a simulation that is one physical process that is consistent with the equation—there could be other processes. In a Graphical or Diagrammatic Jeopardy Problem, the student might see a kinematics graph or a work-energy bar chart that evolves with time on the simulation screen. The student then invents a process that is consistent with the graph or bar chart. Finally, a version of the simulation is run that shows one possible process that is consistent with the graph or bar chart. These types of activities can be produced with *Interactive Physics*[13] and are included in *ActivPhysics*.[14]

V. STRENGTHS AND WEAKNESSES OF JEOPARDY PROBLEMS

If one of our instructional goals is to promote problem solving with understanding, Jeopardy Problems have several strengths. First, students often think of traditional physics problem solving as a process for finding the right equation. For Jeopardy Problems, students cannot use formula-centered, plug-and-chug problem-solving methods. Instead, they must give meaning to the symbols in the equations and to the diagrams and graphs. They must visualize a process that is consistent with the equation, diagram, or graph. The equations, diagrams, and graphs become short stories about life. The mathematical relations in Equation Jeopardy Problems are models of physical situations rather than just something into which students plug numbers.

A second strength of these problems is that units become more meaningful since they become the key to determining what physical quantities are involved. If we are dealing with the pressure in a standing fluid, then the quantities that will appear in one or more of the terms in the equation will be density, acceleration due to gravity, and a distance. The units are the key to recognizing each of these quantities. Consequently, the units become useful sources of information.

A third strength of these problems is that they help the students learn to translate between representations in a more robust manner. By robust we mean that they develop a stronger understanding of each representation—the verbal problem statement, the everyday picture-like representation, the physics representation, and the mathematical equation. They also learn to convert one representation into another and in any direction. To do this, each representation must have meaning for the student.

A fourth strength of these problems is that they are easy to create. All you need is an existing problem from the back of the chapter of a physics book. Simply apply in equation form the fundamental principle needed to solve the problem. You have a Jeopardy Equation Problem. Or construct a diagram or graph that describes the problem. You have a Jeopardy Diagram or Graph Problem.

A fifth strength of Jeopardy Problems depends on their use in homework assignments and on tests. If students realize that Jeopardy Problems will appear on tests, the students are encouraged to think more deeply about standard end-of-chapter problems and to use multiple representations of physics processes to describe these problems.

A weakness of Jeopardy Problems stems from the fact that they are novel for students. Any new problem format has some learning associated with it that is independent of the particular problem content. Students develop mechanisms for coping with free response, multiple choice, and essay questions on tests. They need practice with Jeopardy Problems before they are used on tests. It is important to start with relatively easy one-equation examples so students develop skill at solving such problems.

There might also be concern about grading these problems. The authors find them easier to grade than standard problems presented in a free-response format. For Jeopardy Problems, students present diagrams, graphs, bar charts, and sketches as part of the solution—seldom seen with traditional problems. The problems can even be presented in a multiple choice format by asking students to choose the one of five versions of one representation (for example, five graphs) that best matches the description of a situation in the form of another representation (for example, an equation).

VI. IMPACT ON STUDENT LEARNING

The authors use one or more pedagogical innovations in their courses (Active Learning Problem Sheets, Context-Rich Problems, ActivPhysics interactive simulations, Ranking Tasks, and Jeopardy Problems). It is difficult to say what impact any one of these innovations has on student learning as measured by various types of tests. The widely used Mechanics Baseline Test (MBT), a problem-solving test with a strong conceptual base, might be one of the better measures of students' ability to use the math language of physics with understanding—a main goal for using Jeopardy Problems. During the last two years, one author (AVH) has taught calculus-ready freshmen engineers—honors students in their engineering course. Jeopardy Problems were used routinely on their tests. They scored 78 on the MBT during the winter of 1997 and 77 during the fall 1997. These scores are equal to and perhaps slightly higher than the best scores reported by Hake for 3259 students from different colleges, including a prestigious Ivy League university.[15] The fall 1997 class scored 86 on the Force Concept Inventory Test, a qualitative reasoning test concerning mechanics. Representing physical processes in multiple ways, including the use of Jeopardy Problems, we believe has a very positive effect on students' ability to use the math language of physics with understanding.

What do students say about Jeopardy Problems? One of us (DVM) has used Jeopardy Problems as homework assignments in a calculus-based introductory physics course. At the end of each semester, he asks students to identify the five homework assignments from which they learned the most and the five assignments from which they learned the least, and to explain why. One class was also asked to identify the advantages and disadvantages of each problem type. Jeopardy Problems were identified as difficult. Several student comments follow:

> ''The advantage of this type of homework was the use of looking at equations and seeing how they apply in the real world.''
>
> ''I spent a very long time on this one, repeated it over and over. I think because it gave the force equations and ask to draw free body diagrams and a physical situation it forced me to analyze the equations until I knew exactly what everything meant.''
>
> ''Even though I hated this one, it made me think ... *a lot*. Instead of just giving me the situation and asking me to find the answer, you turned the tables and had me work through the situation the opposite way I normally would have. I had to use the equations and come up with a reasonable physical situation and this was you could say rather 'stimulating.' ''

Learning to *read* with understanding the equations of physics is a challenging task for our students and a task that is not addressed by typical end-of-chapter problems.

VII. SUMMARY AND CONCLUSION

This article has presented a new format for physics problems. The format essentially reverses the usual solution sequence by providing the mathematical equation as the starting point, normally the next to last point of the solution process. Solvers then construct from the equation one, or more, of the following: a physics representation, an everyday picture-like representation, or a verbal description of the physical situation. Other versions of Jeopardy Problems start with diagrams, graphs, or bar charts. A wide variety of problems can be developed using this format. These problems range in difficulty from reasonably straightforward to very complex. The format is useful in all topic domains of physics and at all levels of physics—remember Feynman's *S*-matrix problem.

The value of this problem format is that it helps students develop a new perspective for both the problem-solving process and for the use of different representations to model physical processes. The equation description of a process is now regarded more as a short story about some aspect of life—about a physical process—and less as a set of symbols that must be solved numerically to answer a question. The problem solution becomes an effort to represent a physical process in a variety of ways—sketches, diagrams, graphs, and equations—more like the method used by experienced physicists when analyzing problems. Jeopardy Problems help students develop a better understanding and appreciation for the representations needed to solve problems with understanding.

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PITY THE POOR OBSERVER

My search consisted mainly of concerning any physicist I chanced to meet at a cocktail party and asking, ‘‘Why is it so important to know the exact speed of light?’’

Most of the answers only puzzled me. One was that the speed of light is one of the few ‘‘constants’’ in nature, unaffected by the motion of the source of light or that of the observer. What observer, I wondered. I was to hear a lot about this unfortunate creature before I had finished. He was forever on board a train, going toward nowhere in particular, and never even allowed to comment upon the phenomena he observed. Aristotle stood him on the earth, Copernicus and Kepler put him up in the sky, and Einstein had him locked in an elevator, plunging down an endless shaft.

Dorothy Michelson Livingston, *The Master of Light—A Biography of Albert A. Michelson* (The University of Chicago Press, Chicago, 1973), pp. 5–6.