Module 5: Analysis of Physics Problems and Test Questions

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Module 5 Analysis of Physics Problems and Test Questions

Introduction

You may be wondering how to apply the concept of developmental stages in your physics teaching. To help you with this, we have prepared modules 5-11 dealing with differing aspects of instruction. Module 5 concentrates on the analysis and writing of physics problems and test questions. As you read the examples we have selected, keep in mind the characteristics of concrete and formal thought described in Module 2. A matter that we find difficult to resolve concerns how to give all students, regardless of the reasoning patterns they use initially, practice in problem solving. Furthermore, evaluation through tests should give all students an opportunity to show what they have learned in physics and with respect to formal reasoning patterns. The article "Physics Problems and the Process of Self-Regulation" by Anton E. Lawson and Warren T. Woolam in Module 11 describes how problems could be used to advance students' reasoning.

Objectives

To assist you in classifying physics problems (homework or test) as "concrete" or "formal."

To assist you in writing physics problems that are "concrete" or "formal," as needed.

Procedure

This module provides for a sequence of activities in which you will study twelve physics problems. The first four serve as background for our explanation of how a problem's demand for concrete or formal reasoning may be identified. The last eight are examples to which we and you can apply the criteria. Please find a partner with whom you can work and exchange ideas during this module. Then use the activities in the attached instructional materials in the order given.
Module 5 Instructional Materials

1. Exploration

The first problem we are presenting here has been given to students in an engineering physics course, and some of their solutions are reproduced on the next page. The students had not covered lens optics in their course, so that they had to rely on general problem-solving strategies rather than on a memorized equation. Note the extent to which students A and D engaged in self-regulation, beginning to advance to a higher level of reasoning because of discrepancies they perceived in their first results. Students B and C did nothing further, apparently satisfied with their accomplishment and oblivious to the inconsistencies and dimensional errors.

Problem 1  (a) The focal length of a convex lens is the distance from the lens where light from a distant source comes to a focus after it passes through the lens. (See Figure 1.) The focal lengths of two identical, thin, convex lenses are the same and measured to be 20 cm each (\( F_1 = 20 \text{ cm}, \ F_2 = 20 \text{ cm} \)). The two lenses are placed one over the other as shown in Figure 2 and taped together at their edges only. The focal length of this combination, \( F_C \), is 10 cm. Write an equation that gives the focal length of a lens combination that consists of two lenses having identical focal lengths.

(b) One of the 20 cm focal length lenses is replaced by a lens having a focal length (\( F_3 \)) of 5 cm. The focal length of the resulting combination is measured to be 4 cm. Write an equation that can be used to calculate the focal length of a lens combination that consists of two lenses of unequal focal lengths.
**Answer (a)**

Student A: If \( F_1 = F_2 \), then
\[
F_c = \frac{1}{2} F
\]

**Answer (b)**

However, since the same principles are acting when the lenses are identical and when they are different, the equations for the two systems should be the same. So I really don't know how to derive the equation.

\[
F_d = F_1 + F_3
\]

\[
F_d = 30 + 5 = 35
\]

\[
6.25 \cdot F_d = F_1 + F_3
\]

\[
F_d = F_1 + F_3 = 6.25
\]

**Student B:**

\[
F_c = \frac{F_1 + F_2}{4}
\]

**Student C:**

\[
F_c = \frac{F_1 + F_2}{4} \quad \text{iff} \quad F_1 = F_2
\]

\[
F_c = \frac{F_2}{F_3} \quad \text{iff} \quad F_3 < F_2
\]

**Student D:**

Several possibilities

\[
F_t = \frac{F_1 + F_3}{4}
\]

or

average \( \frac{\text{focal length}}{\text{number of lenses}} \)

\[
(\frac{1}{F_1} + \frac{1}{F_2}) = \frac{1}{F_t}
\]

This is not obvious and is not consistent with the other problem.

\[
F_1 = 30, \quad F_2 = 30, \quad F_t = 10
\]

\[
F_1 = 30, \quad F_2 = 5, \quad F_t = 4
\]

\[
\frac{1}{F_1} + \frac{1}{F_2} = \frac{1}{F_t}
\]

At 1st:

\[
\frac{1}{30} + \frac{1}{5} = \frac{1}{10}, \quad \frac{1}{30} = 10
\]

\[
\frac{1}{5} + \frac{1}{30} = \frac{1}{25}, \quad \frac{1}{30} = 4
\]

\[
\frac{1}{F_1} + \frac{1}{F_2} = \frac{1}{F_t}
\]
Now please write out solutions to Problems 2, 3, and 4, making a sketch and carefully stating the equations (definitions, laws, principles) that are the starting point of your procedure.

Problem 2  At what distance from the earth's center would a standard kilogram weigh 1 newton? At what distance would a body with a mass of 1 gram weigh 1 dyne?

Problem 3  An unbalanced force of 5.0 newtons on an object produces an acceleration of 20 meters/sec². What is the mass of the object?

Problem 4  An inductor made of copper wire has been wound on a long cylindrical form of cross-sectional area $10^{-3} m^2$. The field at the center of the inductor is 0.1 webers/m² when the current is 4.0 amp. The resistance of the winding is 25 ohms and its inductance is 0.2 henry. How long is the winding on the form?
2. Criteria for Classifying Problems as "Concrete" or "Formal"

You have probably assessed the three problems to be of quite differing difficulty, with #3 the easiest and #4 the hardest. How would students react to them? Problem 3 can be solved by direct substitution into Newton's second law which relates force, mass, and acceleration. A student who uses concrete reasoning patterns and has memorized the terminology and the law should be able to do that, even though he does not understand all the ramifications of Newton's law when applied with various kinds of boundary conditions. We, therefore, call Problem 3 a "concrete" problem.

Problem 2 is more difficult even if the student has memorized the form of the law of gravitation in terms of the acceleration of gravity at the earth's surface, which is not mentioned in the problem statement. Coordinating the law of gravitation with the definition of weight and the conditions at the earth's surface requires formal thought; hence we consider Problem 2 to be a "formal" problem.

Problem 4 would strike the concrete thinker as completely impossible, since the length of the winding is usually not stated explicitly in formulas for inductance and magnetic field that he can memorize. To solve the problem, the student has to realize that the magnetic field depends on the density of windings while the inductance depends on the total number of windings. Since both the field and the inductance are given, the length can be found. The resistance, which depends directly on the length of wire, according to a very popular formula, is useless here, because resistivity, wire diameter and form shape are not given.

From these three problems certain patterns are visible, and we shall now expand them to formulate a classification into "concrete" problems (solvable by concrete reasoning patterns through straightforward use of a learned definition or equation) and "formal" problems (solvable only after an overall analysis and some improvisation). Here are some clues for distinguishing between the two types:

Clues for "concrete" problems -- affirmative answers to:

C1. Can I use a formula to solve the problem?
C2. Could I observe the variables in the problem directly?
C3. Are the calculations simple, not requiring proportions, graphical interpretations of abstract variables, or choosing among models or theories?
C4. Are the given data necessary and sufficient?

Clues for "formal" problems -- affirmative answers to:

F1. Do I need to combine formulas or derive a new one?
F2. Do I need to introduce variables in addition to the ones given or asked about?
F3. Do I need to decide which approximation or theory is appropriate to the conditions of the problem?

F4. Do I need to select relevant data from the extraneous or be concerned that the problem might admit no solution or more than one solution?

F5. Do I need an overall plan before I can start with an equation?

3. Applications of the Criteria

Keep these clues in mind as you examine Problems 5 to 7, which will serve to illustrate the classification scheme further. We suggest that you not spend time now actually working out solutions.

Problem 5 What is the displacement of a car that travels at a steady speed of 40 miles/hour for three hours on a straight road?

Concrete -- all the items above, especially C1.

Problem 6 A space capsule travels along a straight line from the earth to the moon. Considering only the earth-moon system, at what distance from the earth is the gravitational force on the capsule equal to zero? Introduce symbols for astronomical data such as distances.

Formal -- especially F1, F2, and F5.

Problem 7 Find the momentum and energy of a 150-grain 30-06 bullet with a speed of 2500 ft/sec. How fast must a 200 lb. deer move to have the same momentum? (7000 grains = 1 lb.)

Formal -- "yes" on C2 and C4, but also "no" on C3. The grains-pounds conversion leads us to this classification, but we admit that the problem may fall between the two types.

Now classify the following problems using the clues described earlier together with any criteria that you have developed. Please write your answers and reasons and compare them with your partner's.

Problem 8 A man in a sailboat is stranded in a dead calm. He wishes to reach an island whose shore is at a distance D from his location.

(a) Suppose he tries to propel himself by throwing an object of mass m off the boat. In what direction should he throw it? Make a diagram.

(b) Suppose the boat and its content have mass m and the man throws the object at speed v; how long would it take him to reach the island? (Neglect friction.)

(Circle one) Concrete Formal
Problem 9  A cue strikes a billiard ball, exerting an average force of 50 newtons over a time of $10^{-2}$ seconds. If the ball has a mass of 0.20 kg, what speed does it have after impact?

(Circle one)  
Concrete  
Formal  

Reasons (you may refer to the items by number):

Problem 10  At the instant a traffic light turns green, an automobile starts with a constant acceleration $a_x$ of 5 ft/sec.$^2$. At the same instant a truck travelling with a constant speed of 30 ft./sec. overtakes and passes the auto. How far beyond the starting point will the auto overtake the truck?

(Circle one)  
Concrete  
Formal  

Reasons (you may refer to items by number):

Problem 11  Six joules of work is done when a charge is moved through a potential difference of 3.0 volts. How large is the charge?

(Circle one)  
Concrete  
Formal  

Reasons (you may refer to items by number):
Module 5 Review Questions

1. The problem that follows has several parts. With your partner, classify each part as "concrete" and/or "formal"; explain how a part might have either classification, depending on which formulas the student has memorized.

   **Problem 12** A car moving with constant acceleration covers the distance between two points 180 feet apart in 6.0 seconds. Its speed as it passes the second point is 45 feet/second.
   
a. What was the car's average speed between the two points?
   
b. What was the car's speed at the first point?
   
c. What was the car's acceleration?
   
d. At what distance before the first point was the car at rest?

"Concrete" parts and procedures:

"Formal" parts and procedures:

2. Look back at Problem 4 or 6, which were considered to be "formal," and rewrite one of them jointly with your partner so it is accessible to a concrete thinker. If you determine that this task is impossible, please state your reasons.

"Concrete" rewrite: