Assessment of Evidence-based Physics Instruction

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Early Years: “Theory” Only, No Lab

- Before 1860, almost no colleges or high schools provided hands-on laboratory exercises for physics students (just occasional demos)
- Assessment often focused on verbatim recall, expressed through verbal “recitation” or copying of instructor’s notes

Text:

- “Suppose a body to be placed at a distance from the earth, weighing two hundred pounds; the earth would then attract the body with a force equal to two hundred pounds…”

Question at bottom of page:

- “Suppose a body weighing 200 pounds to be placed at a distance from the earth, with how much force does the earth attract the body?”

J. L. Comstock, *A System of Natural Philosophy* (1854), pp. 30-31

Quantitative Problems Became Common

- A stone dropped from the top of tower, struck the ground in 4 seconds: how high is the tower?
- Under the influence of a constant force, a body goes 12 feet in the first three seconds; how far does it go in 18 seconds?

L. C. Cooley, *A Textbook of Natural Philosophy* (1869), pp. 93-94

Student Laboratories Began to Spread

- In 1878, only four high schools and about 30 colleges and universities incorporated full-year student laboratory activities in physics
- By 1900, student laboratories had become commonplace
- Beginning around 1890, students were often required to submit signed laboratory notebooks for college-entrance exams

Lab Assessments

- Most reports of lab assessments focused on scrutinizing students' lab notebooks for completeness, accuracy, and clarity; however, grading rubrics are not available.
- However, one (unusual) research investigation described the following method:

Practical Laboratory Problems. Each student is given a complete set of the apparatus required to solve eight simple practical problems in physics, such as "connect the electric bell to the dry cell so that it will give a single stroke but will not clatter when the circuit is closed" ….The solution of each is recorded on a suitable blank, from which the score is counted.

C. R. Mann, *A Study in Engineering Education* (1918), p. 118.

Physics Teachers Wondered How to Assess "Abstract Aims"

Sub-Committee on Tests, Physics Section, Central Association of Science and Mathematics Teachers:

[School Science and Mathematics **21**, 273 (1921)]

The "highest aim" of physics teaching is development of "initiative, independence of thought and action, keenness of observation, aggressiveness, etc."

"A teacher estimates the effectiveness of his teaching…"

1. By the attention given by individuals in his classes.
2. By the interest in the subject shown in the questions raised in class…
3. By their care in the use of apparatus and their attitude towards experimentation.
4. By their growth in keenness of observation and their ability to grasp the meaning of experiments.
5. By their ability to generalize rationally from experimental results.
6. By the growth in the power to apply general principles to new and complicated cases.

The teachers were *"unanimous in criticizing adversely the proposal to ascertain these same points by a questionnaire or test….*

…a profitable set of questions [might be] evolved…but they feel quite incompetent to submit such a test [at the present time]."

Qualitative, Quantitative, and "Define or Describe" Questions were Used

- On the first college entrance exams (1901-1904), it was difficult to discern the examiners' intent on many of the non-quantitative questions, and there was much dissatisfaction with the "arbitrary" grading
- Number of examinees jumped from < 200 in 1901 to ≈1000 in 1915, to > 2000 in 1919
- Later exams (1915-1920) put greater emphasis on quantitative problems

College Entrance Examination Board

Post-Office Sub-Station 84, New York, N. Y.

PHYSICS

Monday, June 20 2.55–4.25 p. m.

In this examination 40 counts will be based on the laboratory note-book submitted by the candidate and 60 counts on the following questions. The candidate is to answer six questions, selecting one from each of the groups (A, B, C, D, E and F).

A

1 A wooden block whose specific gravity is 0.75 weighs 48 grams. If the block were floated in water with what force would one need to push downward upon it to hold it under water?

2 Draw and describe the essential parts of a mercurial barometer. Account for the change in the height of the column of mercury (*a*) when the barometer is carried to the top of a high mountain, (*b*) when carried to the bottom of a deep mine.

B

3 Using the formulae for free fall and a formula for work, prove that the expression for kinetic energy should contain velocity squared.

4 Why is the vibration frequency of a spring practically the same for all amplitudes?

C

Comprehensive Examination

PHYSICS

Friday, June 22 — **2–5 p.m.**

A teacher's certificate covering the laboratory instruction must be presented as a part of the examination, unless the laboratory notebook is to be presented at a laboratory examination.

Answer ten numbered questions, distributed as follows: three from Group I, two from Group II, two from Group IV, two from Group V, and one of the remaining questions.

The number in parenthesis before each question indicates the number of credits assigned to it.

Show clearly the method by which you obtained your answers to problems and state the units used in each case.

Attach to the answer, in each case, the number and letter used in the printed paper.

Group I

1. If a 10-gram body should start from rest down a frictionless plane and gain in six seconds a velocity of 120 cm. per second, what would be:

a) (2) the total distance covered?
b) (2) the distance covered during the first second?
c) (2) the distance covered during the last second?
d) (2) the acceleration?
e) (2) the kinetic energy at the end of six seconds?

2. *a*) (2) Define horse-power.
b) (6) An automobile running at the constant rate of 30 miles per hour exerts a force of 200 lbs. in the direction of motion. What is the power supplied to the wheels of the automobile?
c) (2) If the efficiency of the transmitting mechanism is 75 per cent, what horse-power is the engine developing?

3. *a*) (7) A uniform plank, *AB*, 12 ft. long and weighing 80 lbs., is used as a "diving-board." End *A* is fastened to the floor of a float. Four ft. from *A* the plank rests on the slightly raised edge *C* of the float, so that 8 ft. of the plank projects over the water. A boy weighing 100 lbs. stands on end *B* and a second boy of 60 lbs. weight, 1 ft. from him. Under these conditions, how strong must the fastenings be at *A*?
b) (3) What is the direction and magnitude of the force exerted at *C*? Make a diagram.

Influence of Educational Psychology

- E. L. Thorndike, early psychometrician, promulgated “completion” tests for physics that influenced physics educators in the early 1900s
- Sentences with missing words were given to students, who had to fill in the blanks; focus was on memorizing definitions and textbook statements, word-for-word.

desirable in examinations in science, a time limit of 30 minutes per set seems the best. One-fourth of a two-hour examination may profitably be spent on such a completion test.

THE I. E. R. PHYSICS COMPLETION TEST
FORM 1.

WRITE YOUR NAME HERE..

Read the statements below. Write words (or numbers) in the empty spaces so as to make them true statements of facts and laws of physics. Read each sentence or paragraph all through and think what words are needed for it before you write any in. Then write them in. Then go on to the next number.

1. 100 centigrade degrees equal..............Fahrenheit degrees.
2. The angle......................is equal to the..............................incidence.
3. ....light is a mixture of all the colors of the spectrum, from ....to.............................inclusive.
4. Surfaces which are......................absorbers of ether radiations are also..................radiators. From this it follows that surfaces which are ....reflectors, like the polished metals, must be...................... radiators.
5. The mechanical advantage of a system of pulleys, provided no energy is dissipated inside the pulleys, is .... the number of..............................of the cord supporting the load.
6. When a mass of air is heated.. its volume increases......................of its value at 0 deg. C. for every rise of 1 deg. C. in temperature.

Some Researchers Recognized the Need to Investigate Students' Ideas

"…the important outcome of this study is not the fact that these students do not generally have scientific concepts, but the knowledge of just what type of notions exist, for it is on these vague and naive notions that more complete and ultimate scientific concepts will have to be built.…

[O. F. Black, *The Development of Certain Concepts of Physics in High School Students: An Experimental Study* (1931)]

Table 34.

PART 2. QUESTION 2a.

An object is compressed to half its size. What effect has this on its mass?

Grade	—8	—9	—10	—11	—12	+9	+10	+11	+12
Number	114	120	115	125	100	172	86	178	192
No effect	1.7	4.2	5.2	3.3	7.0	4.7	27.9	44.9	37.5
Mass is half	17.6	23.3	20.8	25.6	37.0	35.5	62.8	32.6	53.1
Mass is doubled	0.0	1.7	0.0	0.0	3.0	3.5	2.3	3.4	3.1
No answer	80.7	70.8	74.0	71.2	53.0	56.3	7.0	19.1	6.3

PART 2. QUESTION 2c.

An object is compressed to half its size. What effect has this on its Mass. Why?

Vol. (size) half, therefore, mass is half	12.3	19.2	17.4	20.8	25.0	24.4	41.9	28.0	42.2
Mass or quantity of mat-									

Table 35.

QUESTION 3a.

An object is taken miles away from the earth's surface. What effect has this on the Mass of the object? *Why?*

Grade	—8	—9	—10	—11	—12	+9	+10	+11	+12
Number	114	120	115	125	100	192	86	178	192
1) No effect	6.2	7.5	6.1	14.4	14.0	16.3	57.0	65.1	68.8
2) Mass gets less	5.3	4.2	8.7	6.4	8.0	21.5	23.2	21.4	26.0
3) Mass gets more	14.9	16.7	15.7	13.6	11.0	9.9	2.3	1.7	1.0
4) No answer	73.6	71.6	69.5	65.6	67.0	52.3	17.4	11.8	4.2
REASONS:									
1) Gravity does not affect mass	0.0	0.0	0.0	1.6	1.0	1.7	10.5	14.6	13.5
Mass always is the same	0.0	1.7	0.0	0.0	1.0	3.3	24.4	24.8	21.8
Gravity gets less further from the earth	.8	1.7	2.6	2.4	4.0	15.8	17.4	15.6	11.5
Gravity more the higher you go	1.7	2.5	3.5	4.0	2.0	2.3	0.0	0.0	0.0
Weight involved	5.3	5.8	4.3	7.2	9.0	7.0	4.7	3.4	7.3
*Miscellanecus	4.4	3.3	5.2	4.0	5.0	4.7	4.7	2.8	5.7
No reason	87.8	85.0	84.4	80.8	78.0	65.2	38.3	38.3	40.2

**Non-Science*: Because it is farther from the earth. It is cold high up. It does not get any bigger. It is still all there. The whole thing is still there. It is the same size. It will expand.

Table 36.

PART 2. QUESTION 3.

An object is taken miles away from the earth's surface What effect has this on the weight of the object? *Why?*

Grade	—8	—9	—10	—11	—12	+9	+10	+11	+12
Number	114	120	115	125	100	172	86	178	192
No effect	12.3	9.2	10.4	12.0	11.0	9.9	9.3	6.1	3.1
Weight decreases	10.5	11.7	20.8	28.8	24.0	46.4	62.9	79.6	82.3
Weight increaes	2.6	6.7	7.0	5.6	3.0	22.0	20.9	10.1	4.7
No answer	74.6	72.4	61.8	53.6	62.0	21.7	7.0	5.6	9.9
REASONS:									
Farther from the earth hence gravity not so strong (or) force of gravity less	1.7	5.0	4.3	6.4	6.0	16.3	37.2	53.4	57.3
Air pressure is less (or more)	3.5	3.3	6.1	4.8	7.0	10.5	8.1	9.5	8.3
Nothing has been added or taken away	7.1	6.7	7.0	7.2	6.0	3.5	4.7	3.4	2.6
*Miscellaneous	4.4	4.2	6.1	7.2	9.0	12.2	14.1	10.7	12.5
No reason	83.3	81.0	76.5	74.4	72.0	57.5	35.9	23.0	19.3

*(Non-Science): It is colder the higher you go. (2.6%) Because the higher you go the less (or more) the weigh becomes. The weight of a thing is always the same Position makes no differense to weight. Because it i taken farther from the earth (2.1%).

IDENTIFICATION OF ABILITY TO APPLY PRINCIPLES OF PHYSICS

[1941]

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The Principles Test, Form A

DIRECTIONS: This is NOT a speed test. Think carefully before answering the questions.

FIG. 1 FIG. 2 FIG. 3 FIG. 4 FIG. 5

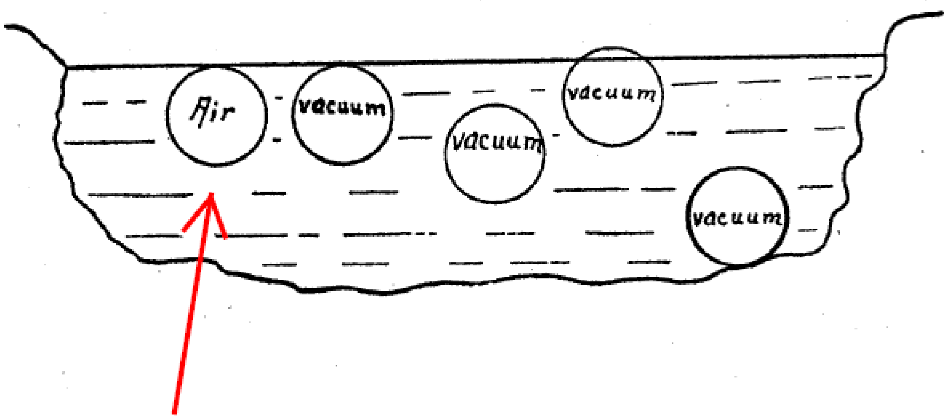


Figure 1 shows a steel tank floating so that it just touches the surface of the water in a pond. If the tank were removed from the pond, had the air pumped out of it with a vacuum pump, and then were sealed and thrown back into the pond, the position which it would take is shown by Figure —.

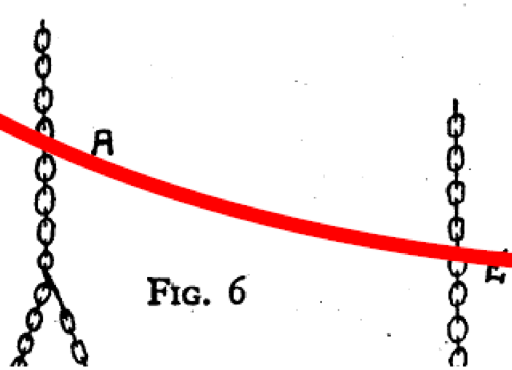
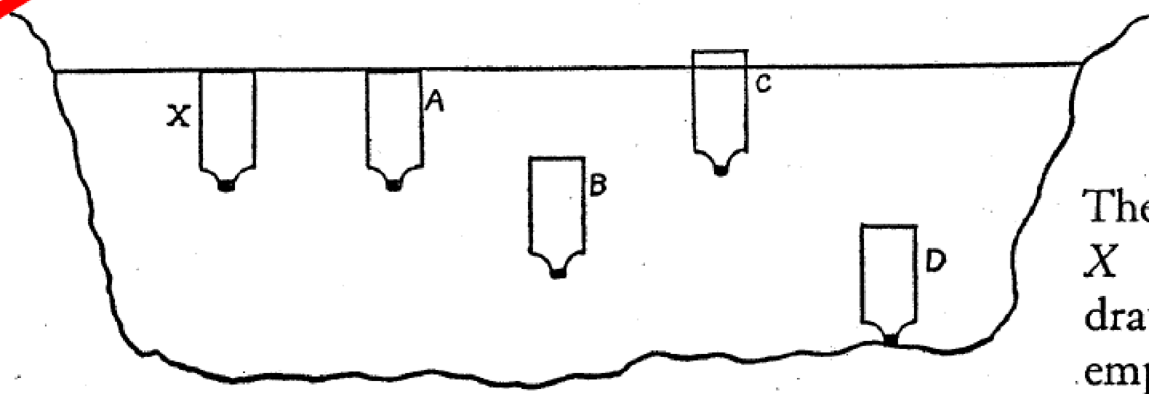


FIG. 6

Figures 6 and 7 show two ways in which a chain may be used in lifting a stone. The chain is more likely to

The Principles Test, Form B

THINK CAREFULLY before answering these questions.



The bottle marked *X* in the above drawing is a sealed empty bottle floating so that it just touches the surface of the water in the pond. If the bottle were removed from the pond, had air forced into it with a tire pump, and then were resealed and placed again in the pond, the position which it would then take is most nearly indicated by the letter ___.

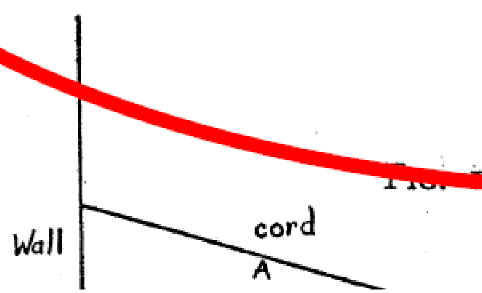


FIG.

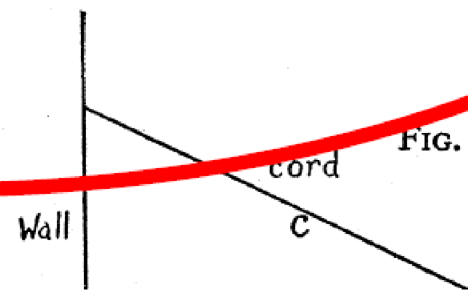


FIG. 2

Summary

- Physics teachers have always struggled to assess students' performance on a wide range of learning goals
- Quantitative problems became a default assessment mechanism very early on
- Memorization exercises have long played a role in physics assessments
- A few early investigators probed students' ideas in depth through interviews and conceptual diagnostics