Implementing, documenting, and assessing evidence-based physics instruction

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Thoughts of an Early Researcher in Physics Education:

"…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.…

“…The fact that a concept has not become scientific through the study of science does not necessarily mean that no conceptual development has occurred. In some cases it is possible to trace development in significance from ‘absolute absence of content’…through various stages of vague notions up to perfectly scientific concepts.…

"…Certain common, vague or erroneous notions of science students were found to have been held before the period of formal science instruction, that is, the presentation of the appropriate subject matter appeared to have had no effect on original notions. Instruction specially directed at these erroneous notions seems to be necessary in addition to the ordinary presentation of subject matter. The mere statement of a fact or hypothesis or the routine laboratory demonstration may not necessarily induce the pupil to reconstruct his preconceived notions of long standing, in fact, it may even confuse him still more."

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

Evidence-based Instruction in Physics: The Beginnings

- Physics educators in the early 20th century argued passionately about optimum methods for teaching physics
- Around 1910, educators began to recognize the need for systematic research to improve the quality of physics instruction, and to help resolve the disputes
- A few dozen research studies were published from 1910-1945; they focused on (1) documenting the degree of student learning, and (2) testing the efficacy of newly developed instructional methods and curricular materials

Early Assessment of Students' Thinking

"I have generally found very simple questioning to be sufficient to show the exceedingly vague ideas of the meaning of the results, both mathematical and experimental, of a large part of what is presented in the texts and laboratory manuals now in use."

H.L. Terry, 1909
Wisconsin State Inspector of High Schools

Probably, one of the most significant truths learned through our recent [physics] testing programs, is the failure of students to accomplish any large fraction of the supposed requirements of courses pursued. In other words, what the teacher thinks he is teaching is usually many times what he actually teaches. Or, the other way round, the pupil is learning but a very small part of what the teacher thinks he is learning.

[A. W. Hurd, “Achievements of students in physics,” Science Education **14**, 437 (1930)]

Early Research on Physics Learning

- Most research focused on analysis of high school instructional methods (e.g., Clemensen [1933]; Hurd [1933])
- There were a few investigations of high school students' ideas in physics (e.g., Black [1931], Kilgore [1941])
- Only a small number of investigations of physics education at the university level (e.g., Hurd [1927-1930], Rudy [1941], Kruglak [1950-1970])

Early Research on University Physics Students

- ***A. W. Hurd (1927-1934):***
  – Taking lab or changing class size had no significant effect on performance in college physics courses

- ***J. Rudy (1941):***
  – University students who had taken high school physics received higher grades than those who had not taken high school physics

- ***Haym Kruglak (1950-1970):***
  – no difference in performance on a theory test between students who had lab, and those who did not

→ Research at the university level was *not* tied to curriculum development or changes in instructional practice

Examples of High School Research Methodology

- **Hurd (1933):** Develop curricular materials (workbook, etc.) directed at desired “applications-oriented” outcomes, test efficacy using pre- and post-tests
- **Kilgore (1941):** Develop and administer concept test (pre- and post), to determine efficacy of concept-focused instruction using “Organization Sheets”
- **Black (1931):** Investigate students’ ideas in depth; test efficacy of special instruction emphasizing qualitative analysis of everyday situations
- **Clemensen (1933):** Develop concept-focused “study outlines” with a guided-question format, test efficacy using standard diagnostic tests

Examples of High School Research Methodology

- **Hurd (1933):** Develop curricular materials (workbook, etc.) directed at desired “applications-oriented” outcomes, test efficacy using pre- and post-tests

“In the [usual treatment], coherency is sought by organization around abstract principles or laws; in this unit, ‘Electric Lighting Systems,’ it is sought by organization around topics of everyday interest. Here principles are introduced to explain; in the conventional textbook, principles and laws are the major interests.”

[A. W. Hurd, *Cooperative Experimentation in Materials and Methods in Secondary School Physics* (1933)]

COÖPERATIVE EXPERIMENTATION IN MATERIALS AND METHODS IN SECONDARY SCHOOL PHYSICS

By

ARCHER WILLIS HURD

INSTITUTE OF SCHOOL EXPERIMENTATION
TEACHERS COLLEGE, COLUMBIA UNIVERSITY

[1933]

COÖPERATIVE EXPERIMENTATION IN MATERIALS AND METHODS IN SECONDARY SCHOOL PHYSICS

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[1933]

TABLE II

PERCENTAGES OF CORRECT RESPONSES TO CERTAIN TEST ITEMS FOR THREE SUCCESSIVE YEARS

Test Item	Percentage of Correct Responses					
	1929–30		1930–31		1931–32	
	Preliminary	Final	Preliminary	Final	Preliminary	Final
1. What voltage is commonly used in city incandescent lighting?	67	92	64	92	47	89
2. What device is used to change the voltage of an alternating current?	21	65	48	71	42	81
3. What voltage change is made when a current enters a residence in a city?	28	67	48	80	40	91
4. What voltage is commonly transmitted through city transmission lines?	4	10	9	54	11	67
5. Incandescent lamps of different sizes are commonly rated in what units?	39	78	71	88	77	97

descent lamp?	10	36	35	84	42	70
18. How much resistance has a house incandescent lamp?	25	67	37	51	4	42
19. How much resistance has a voltmeter?	1	45	2	70	8	37
20. If several conductors are connected in parallel, how do the currents in the various conductors compare?	9	60	1	46	1	19
21. If several conductors are connected in series, how do the currents in the various conductors compare?	44	87	27	46	23	41
22. If eight 485-ohm lamps are connected in parallel with a 115-volt source, find (a) the current in each lamp and (b) the total current. . . . a	1	50	[illegible]	56		

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concisely
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-32 tests,
68.2 per
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ving that
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the total

units?	39	78	71	88	77	97
6. List three sizes of incandescent lamps commonly used. .....one	39	73	71	85	89	97
two	32	70	65	83	86	96
three	29	68	52	68	69	82
7. Name the unit for electric current.	0	41	15	75	13	82
8. Name the device for measuring electric current.	8	72	4	75	13	77
9. Name the unit for measuring E.M.F.	3	57	12	81	10	82
10. Name the device for measuring E.M.F.	7	74	12	89	8	80
11. How is the current changed when more lights in a house are turned on?	12	46	19	47	22	57
12. Name the law stating the relationships among current, E.M.F., and resistance in a direct current circuit.	11	88	16	91	7	80
13. House electric meter readings are made in what units?	8	18	23	56	27	69
14. Electric light bills are computed on the basis of what units?	43	63	34	70	33	70
15. Give the formula showing the relationships among volts, ohms, and amperes in a direct current circuit.	7	53	10	88	6	78

Name .... School ....

City .... State ....

WORK-TEST BOOK

IN

PHYSICS

BY

A. W. HURD

THE MACMILLAN COMPANY

NEW YORK

1932

relatively small..........passes through the coil. The scale is.........., however, to read the number of..........passing through the..........and the.........., which is equal to that in the..........under consideration.

15. Explain how an electromotive force is commonly measured.

An electromotive force is commonly measured by using a........... This is a modification of a current detector called the..........as is the ammeter. It, however, utilizes the..........current passing through it to estimate the..........between the points to which it is connected. It must have a..........resistance so that current passing through it will be so..........that the..........will not be lowered. It is not connected.....the circuit directly but in a..........circuit or........... The scale is properly..........to read..........of..........existing between the points to which it is connected.

16. Explain how incandescent lamps are commonly connected in circuit, and show the advantages of this method.

Incandescent lamps are commonly connected so that each lamp gets a..........of the total current; i.e., in..........with one another. The resistance of each lamp must be..........in order to give light; the voltage for each lamp must be..........in order to supply the proper cur-

IDENTIFICATION OF ABILITY TO APPLY PRINCIPLES OF PHYSICS

[1941]

By

William Arlow Kilgore, Ph.D.

TEACHERS COLLEGE, COLUMBIA UNIVERSITY

CONTRIBUTIONS TO EDUCATION, NO. 840

Published with the Approval of
Professor S. Ralph Powers, Sponsor

IDENTIFICATION OF ABILITY TO APPLY PRINCIPLES OF PHYSICS

[1941]

- **Kilgore (1941):**

(1) Create and administer concept test, pre- and post-instruction;
(2) Carry out concept-focused instruction that made use of self-developed "Organization Sheets" emphasizing "Important Principles of Physics" [mostly expository, with a few questions]

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

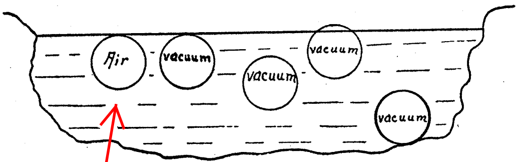


Figure 1 shows a steel tank floating so that it just touches the surface of the water in a pond. If the tank were removed from the pond, had the air pumped out of it with a vacuum pump, and then were sealed and thrown back into the pond, the position which it would take is shown by Figure ___.

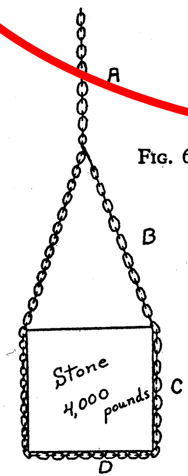


FIG. 6

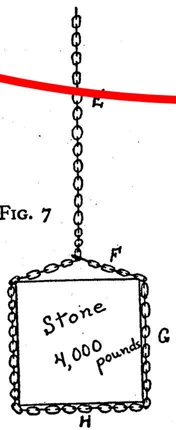


FIG. 7

Figures 6 and 7 show two ways in which a chain may be used in lifting a stone. The chain is more likely to break if it is used as shown in Figure ___.

In Figure 6 the chain has the greatest stress upon it near the letter ___.

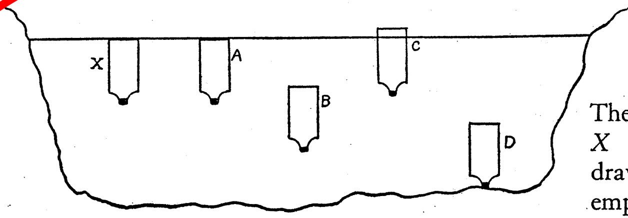
In Figure 7 the chain has the greatest stress upon it near the letter ___.

In selling an improved auto jack a salesman gave the following data:

Height of jack ... 8 inches ... Length of handle ... 4 feet

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. 1

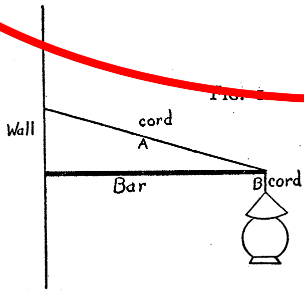
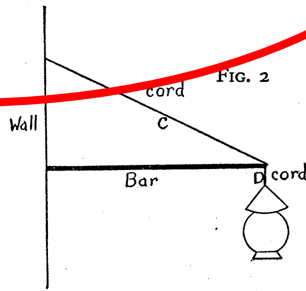
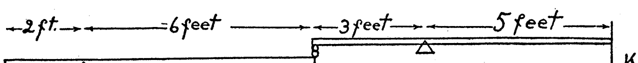


FIG. 2



Figures 1 and 2 show two ways of supporting a heavy lamp by means of a cord and a bar placed against a wall. The cord is more likely to break when the lamp is supported as shown in figure ___.
The cord is most likely to break near the letter ___.



THE DEVELOPMENT OF CERTAIN CONCEPTS OF PHYSICS IN HIGH SCHOOL STUDENTS.

AN EXPERIMENTAL STUDY.

BY

OSWALD F. BLACK, B.Sc., Ph.D.

[1931]

THE DEVELOPMENT OF CERTAIN CONCEPTS OF PHYSICS IN HIGH SCHOOL STUDENTS.

- **Black (1931):**

(1) Investigate students' ideas in depth using written instruments and oral interviews;
(2) test efficacy of special instruction emphasizing qualitative analysis of everyday situations

[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?

	—8	—9	—10	—11	—12	+9	+10	+11	+12
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 matter always same (or) mass independent of volume	0	0	0	0	0	2.9	2.3	23.6	21.9
*Miscellaneous	3.5	3.3	4.3	4.8	5.0	7.0	9.3	14.6	12.5
No reason	84.2	77.5	78.3	74.4	70.0	65.7	46.5	33.8	23.4

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
*Miscellaneous	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.

**Science* (No effect). Because nothing has been added or taken away. It still contains the same quantity of matter. Its size does not change. It is still all there. Density is the same. Air pressure does not change mass. Temperature has nothing to do with mass. Because of gravity. *Gets more*: Air pressure gets less (more). Because of gravity.

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 weight becomes. The weight of a thing is always the same. Position makes no differense to weight. Because it is taken farther from the earth (2.1%).

*(G.S. & Phys.) Weight decreases with height above sea-level (8%). Weight increases with height above sea-level (1.1%). Power of the sun is so great that it would make anything weigh more. Because it is nearer the moon. It will have less energy therefore less weight. It offers less resistance. Weight never changes. Its volume expands therefore it weighs less.

CHAPTER IX.

EXPERIMENTAL TEACHING.

In Part I of this study were given the notions held by children who have and who have not studied General Science or Physics; an estimate of the extent to which any notion occurs having been determined by examination of responses to various questions. These questions were answered by pupils under ordinary school conditions. No real attempt was made, however, to account for the occurence of any particular erroneous notion, or for the small percentage of students who hold particular scientific concepts—the results were just given as representative of existing notions.

It may be claimed, however, that General Science students cannot be expected to hold scientific concepts of Heat and Light as the treatment of these subjects is very elementary as compared to the way the same subjects are studied in the Physics course; it may even be said that certain essential subject matter may not have been treated in the General Sceince course at all. In other words, the question of method and subject matter may be involved.

Although such may be the case, the results of Part 1 are still significant in that they represent the notions children hold under existing conditions of teaching. To answer the question "Does the study of General Science give a child a scientific concept of Light?" we have to take General Science pupils as they are. The same holds in the case of Physics students.

matter, especially since the writer feels that treatment of subject matter was more intense than is usually the case in actual school conditions where so much work has to be crowded into the school year.

Study of Individual Cases.

This method consisted of questioning pupils individually and of following up a response with another question, every question and response being recorded. The purpose of this type of examination was to attempt to find out not only what notion the pupil held, but also why he had the notion.

In this way, the writer examined six pupils of each of the IIth Grades, twelve of group 9X and ten of Group 9Y, after teaching and final testing had been completed.

Case 1. Girl (3). Age: 15—9. I.Q. 99. (Group Y).

Q. When you talk of the mass of a stone, just what do you mean?

A. The quantity of matter in it.

Q. What do you mean by "Quantity of Matter"?

A. The amount of substance in it.

Q. Well, supposing you had two stones how would you know which had the more substance in it?

A. The bigger one.

Q. Supposing there were two objects lying on this desk, and both were equally big, how would you know which had more substance in it?

A. They would have the same amount if they were the same size.

Q. Their masses then are equal?

A. Yes.

Q. If one were lead and the other iron would their masses be equal?

A. Yes, mass has nothing to do with their weights but with the amount of matter in them, and they both have the same amount of matter.

Q. Did you like this kind of work?

A. No.

Q. Why not?

A. Too much algebra. I don't like algebra.

Case 2. Girl (6). Age: 17—11. I.Q. 117. Grade 12. (Group IIY).

Q. When you talk of the mass of a body what do you mean?

A. The quantity of matter it contains.

Q. But what do you mean by "Quantity of Matter"?

A. (No answer.)

Q. Well, supposing you had two objects, how would you know which had the greater quantity of matter?

A. Weigh them—the one that weighs more has more inertia.

Q. So you mean "Quantity of Matter" is its weight?

A. No, but the one that has more weight will have more mass.

Q. How do you know this?

A. Because mass is proportional to weight.

Q. Why?

A. I can show it on paper but cannot explain it. (Paper and pencil were provided.)

$$W_1 = m_1 g \qquad W_2 = m_2 g$$

$$\text{Therefore} \quad \frac{W_1}{W_2} = \frac{M_1 g}{M_2 g} = \frac{M_1}{M_2}$$

Q. Why do you cancel "g"?

A. Because g equals 32 in both cases.

Q. But is g always 32?

A. Yes, at the same place on the earth.

Q. So, what now do you mean by "Quantity of Matter"?

A. I can't explain it....I know its not weight but you can find it by weighing.

Q. Did you like this kind of work?

A. No, I don't like the mathematics part of it.

Case 3. Girl (12). Age: 17—4. I.Q. 115. Grade 12. (Group IIX).

Q. When you talk of the Mass of a body what do you mean?

A. The quantity of matter it contains.

Q. What do you mean by "Quantity of Matter"?

A. The amount of material in it.

Q. How would you know which of two objects contains more material in it?

A. The larger one would.

Q. So, amount of material or mass is the "volume" of the material?

A. No, mass is not volume.

Q. Well, you said the larger one?

A. I mean the heavier one.

Q. So, you mean mass is weight?

A. No, it is not weight.

STUDY OUTLINES IN PHYSICS

Construction and Experimental Evaluation

By

Jessie Williams Clemensen, Ph. D.

TEACHERS COLLEGE, COLUMBIA UNIVERSITY

Contribution to Education, No. 553

Published with the Approval of
Professor S. R. Powers, *Sponsor*

[1933]

STUDY OUTLINES IN PHYSICS

Construction and Experimental Evaluation

BY

JESSIE WILLIAMS CLEMENSEN, PH. D.

- **Clemensen (1933):**

(1) Develop concept-focused "study outlines" with a guided-question format;

(2) test efficacy using standard diagnostic tests

APPENDIX B

SAMPLES OF STUDY OUTLINES

UNIT I. PHYSICAL PROPERTIES AND BEHAVIOR OF LIQUIDS[1]

Problem 1. What causes water to exert force in a faucet or water pipe?

A. What causes liquid pressure?
B. In what direction is the pressure? Why?
C. What causes artesian wells?
D. Water supply systems:
   1) How does your city water system enable you to obtain sufficient pressure at a house faucet? What can you find out about the history of your city water system?
   2) How is the pressure obtained in small towns? In country homes?
   3) What causes the pressure at a faucet to be different at various times?

References[2]
B & B—¶s 54, 57, 61, 77, 74. Exs., p. 95:7,8; p. 71:1,2.
M, G, & P—¶s 18, 21, 27. Exs., p. 14:5; p. 15:10; p. 19:2.
Dull—¶s 22–26, 29. Topics, p. 37.
Lynde—pp. 30–37 (specially interesting).

Problem 2. How is liquid pressure measured? How calculated?

UNIT VI. MAGNETISM AND ELECTRICITY

Sample Page

Problem 5. Effects produced by electric currents.

A. Magnetic Effects

1) How could you use a magnetic compass to determine whether a current is flowing in a wire? In general, how will the needle arrange itself with respect to the wire? How could you tell in which direction the current is flowing?
2) How could you make a magnet with a piece of soft iron, a wire, and a dry cell? What purpose does the soft iron serve? Could you produce a similar magnetic effect without the iron?
3) Trace the current through an electric bell. Exactly what happens to make the bell ring?
4) Diagram a simple telegraph circuit (without book) and explain exactly how it works. How is the ticking sound made? What is the purpose of a relay in some circuits? How does the relay act?
5) How is the magnetic effect of a current used in such measuring instruments as galvanometers, volt-, and ammeters?

References

B & D, pp. 337–346.
M & G, pp. 252–261.
Dull, pp. 375–382.
Lynde, pp. 187–194.
Whit., Secs. 198, 205, 212, 214–229 (good).

"*Remember:* You are not trying to *find* the answer, you are learning *how* to figure it out. Most important is your power to *think*."

APPENDIX C

INSTRUCTIONS ON USE OF STUDY OUTLINES

PART I: INSTRUCTIONS TO PUPILS

Purposes of the Study Outlines.

1. To aid pupils in learning *how to study*.
2. To give pupils definite *goals for each study* period in physics, and to save them time in finding the main ideas of the lesson.
3. To aid pupils in seeing the *relation of each lesson* to the *whole* topic, and of the different topics to one another.
4. To aid pupils in seeing the main points of a topic and their relation to one another for *review*.
5. To aid pupils who must be *absent* to keep up with class assignments.

Note that each of these purposes is to *help you* in some way. You will find it is true; the Outline *will* help you *if* you *use* it.

Summary

- Research in physics education was scattered and uncoordinated before 1970
- Investigations of students’ thinking were rare
- Research was not tied closely to the development of curriculum and instructional methods