How Can the History and Philosophy of Science Contribute to Contemporary U.S. Science Teaching

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What History Teaches Us About Using History of Science to Teach About Nature of Science

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Ubiquity and longevity of NOS

- Helping students develop informed conceptions of nature of science (NOS): A ubiquitous, long-standing, consistent, and central goal for precollege science education reform efforts in the US and around the globe past and present

  (e.g., AAAS, 1971, 1990; Curriculum Council [Western Australia], 1998; Millar & Osborne, 1998; Ministry of Education [Venezuela], 1990; Ministry of Education [Taiwan], 1999; Ministry of National Education [Turkey], 2000; NRC, 1996, 2000; Next Generation Science Standards, ~2012; NSTA, 1982; Pan-Canadian Science Project, 1997; Rutherford, 1964; Wilson, 1954)

An elusive goal

- Research consistently indicates that the larger majority of precollege students and science teachers continue to ascribe to naïve NOS conceptions
- Findings consistent irrespective of how NOS is conceptualized and assessed at the time specific research studies were undertaken

(e.g., Abd-El-Khalick & Lederman, 2000; Carey & Stauss, 1968 ; Dogan & Abd-El-Khalick 2008; Lederman, 1992, 2007; Kang, Scharmann, & Noh 2005; Kimball, 1967-68; Rubba & Anderson 1978; Trent, 1965)

Using history to teach about NOS

- During the past 85 years, historians of science and science educators have repeatedly and consistently argued that history of science (HOS) can play a significant role in helping precollege students and science teachers develop informed NOS conceptions (Conant, 1947; Brush, 1989; Duschl, 1990; Haywood, 1927; Klopfer & Watson, 1957; Matthews, 1994; Monk & Osborne, 1997; O'Brien & Korth, 1991; Robinson, 1969; Rutherford, 1964; Scheffler, 1973; Wandersee, 1992)

What not to ask

- Should HOS be used to impact learners' understandings of NOS?
  - HOS is the 'stuff' of NOS
  - Without HOS, teaching about NOS could be reduced into a set of de-contextualized platitudes
- Can HOS impact learners' understandings of NOS?
  - Graduate students in HOS surely would develop sophisticated understandings of NOS

What to ask

- Whether and how HOS can be used in the context of the realities of precollege science classrooms and/or science teacher education programs to impact learners’ conceptions of NOS?
  - Highly regulated teacher education programs with overly extended agendas
  - Increasingly test-burdened precollege science classrooms with high-stakes consequences (e.g., NCLB, Race to the Top)

What to ask

- How much HOS is enough in terms of developing science teachers' understandings of NOS? Or enabling them to teach *with* and *about* NOS in their classrooms?
- How can we optimize the impact of HOS courses on teachers' understandings and teaching related to NOS?
- What pedagogical approach(es) are likely to optimize the impact of HOS on helping precollege students develop informed or more sophisticated understandings of NOS?

E.g., Impact of HOS courses

- Even though they date back to the mid 1950s, as late as 2000, no systematic empirical studies in science education examined the much-advocated and assumed influence of college level HOS courses on college students’ and science teachers’ NOS views
- The assumed impact was very limited and mediated by a set of instructional factors
(Abd-El-Khalick, 1998; Abd-El-Khalick & Lederman, 2000)

Explicit-reflective NOS instruction

- The label "explicit" does not to refer to any variety of direct or didactic instruction; has no instructional implications
- "Explicit" has curricular implications: Inclusion of specific NOS learning outcomes in any instructional sequence aimed at developing NOS understandings
  - The goal of enhancing learners' conceptions of NOS *"should be planned for instead of being anticipated as a side effect or secondary product of"* engagement with science learning (Akindehin, 1988, p. 73)

Explicit-reflective NOS instruction

- "Reflective" has instructional implications
  - Inclusion of structured opportunities to help learners examine their science learning experiences from within an epistemological framework
  - E.g., reflection on questions about the development and validation, as well as the characteristics of, scientific knowledge

Explicit-reflective NOS instruction

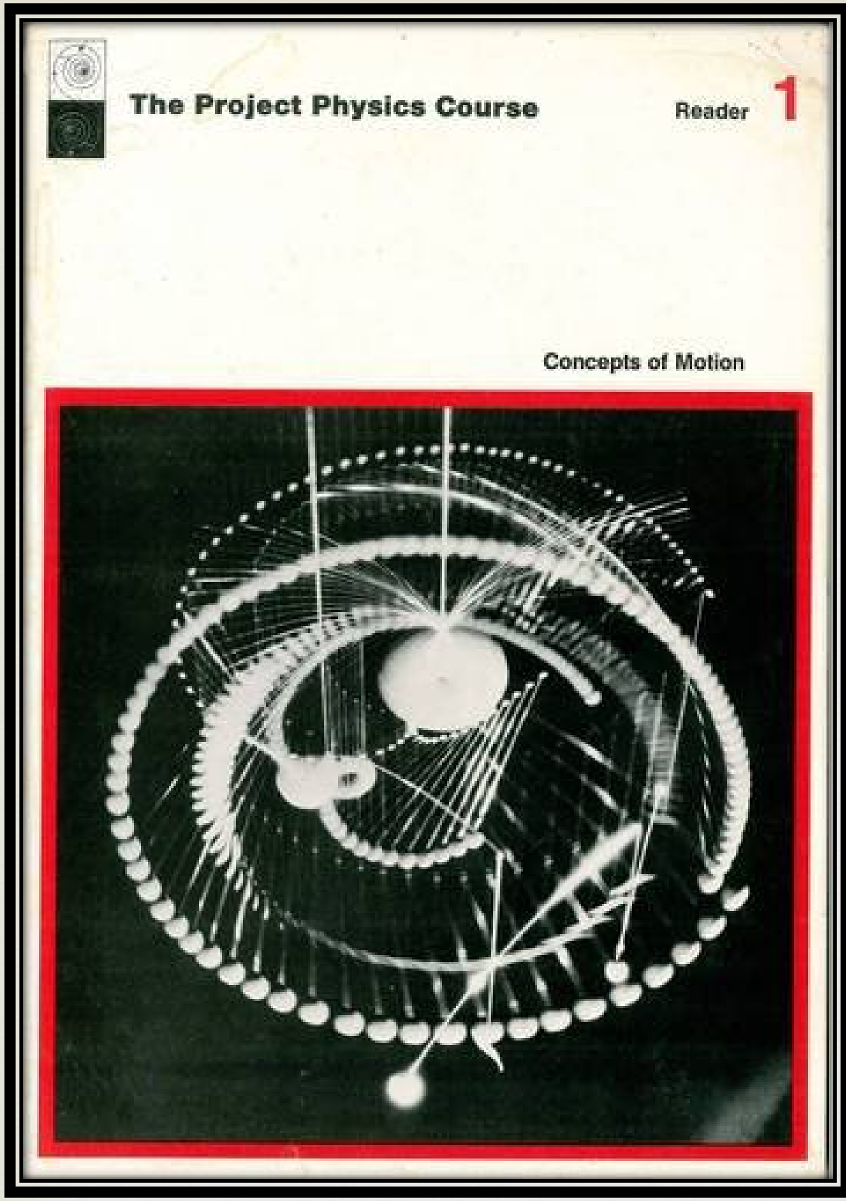
- The inclusion of specific NOS learning outcomes in curriculum and instructional materials does not entail a specific instructional approach
- Approach depends on the outcomes; learner abilities, characteristics, aptitudes, and skills; available resources; etc.
- Strong preference for active, student-centered, collaborative, and inquiry-oriented approaches

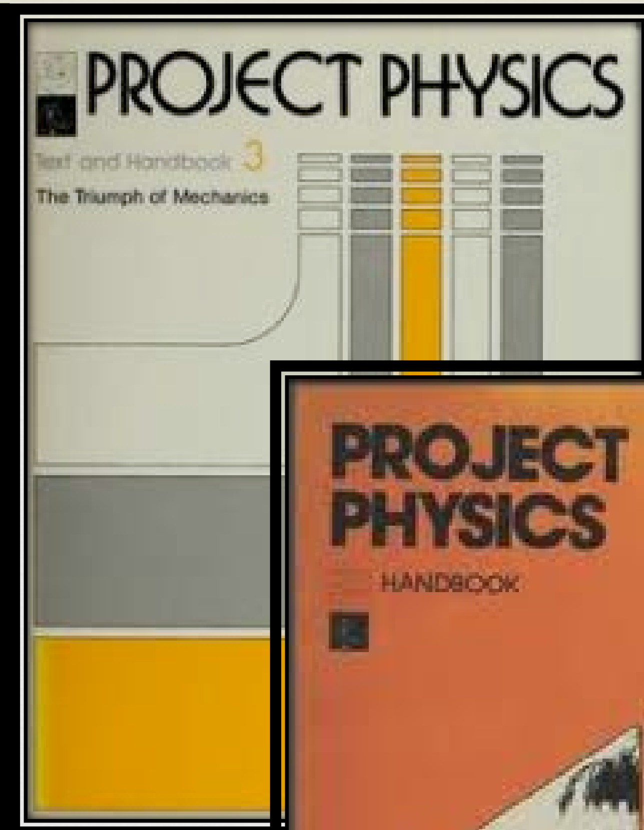
Evidence for impact

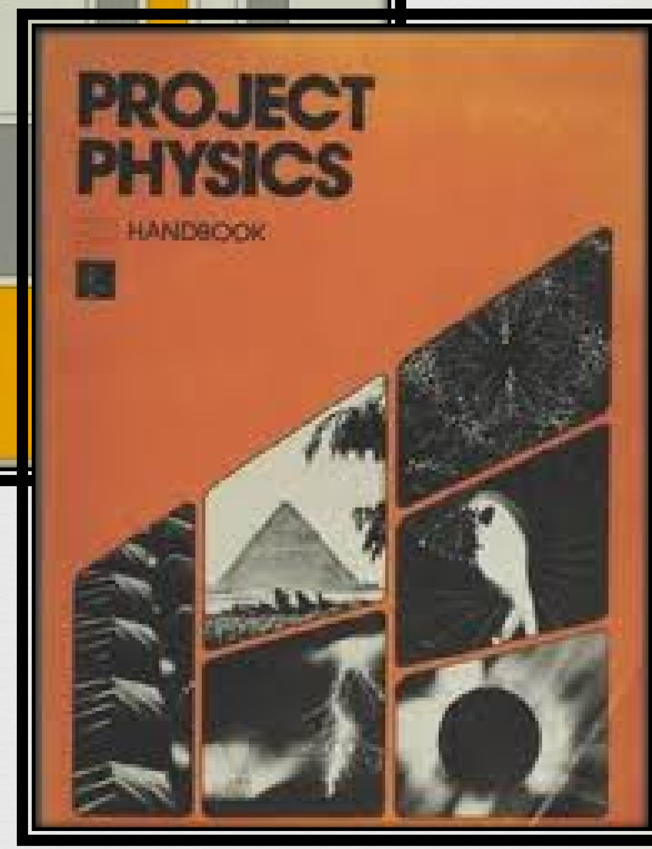
- Interventions that draw on, and/or are embedded within
  - Rich historical case studies (e.g., Howe & Rudge, 2005)
  - Authentic scientific internships (e.g., Bell, Crawford, et al., 2003)
  - Inquiry-based contexts (e.g., Yacoubian & BouJaoude, 2010)
  - Argumentation (e.g., McDonald, 2010), and
  - Meta-cognitive instruction (e.g., Peters & Kitsantas, 2010)

Using history to teach about NOS

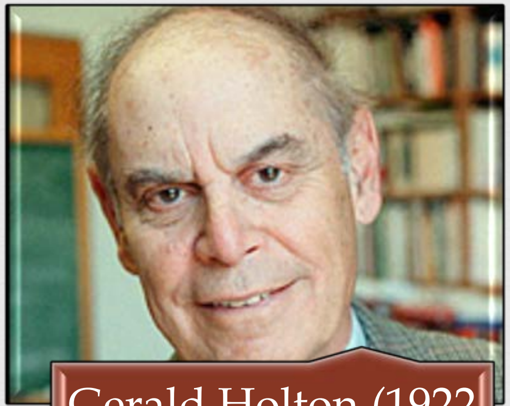
- HOS has been taken to task in the bid to impact precollege students' conceptions of NOS more than 40 years ago
- Part of a large scale national effort that involved thousands of teachers and tens of thousands of precollege students



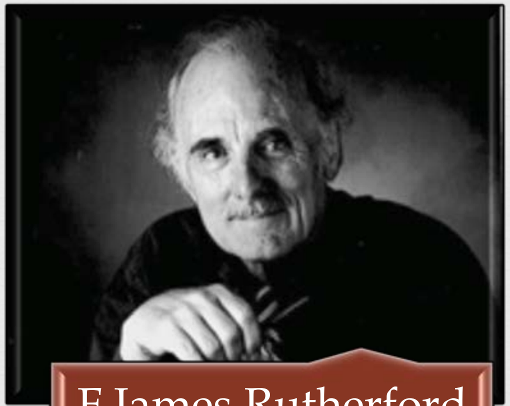




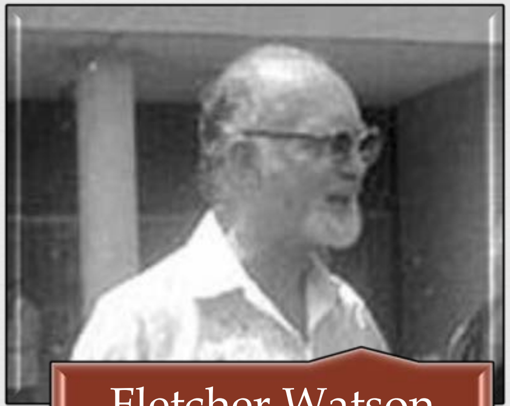
(Harvard) Project Physics Course (~ 1962 – 1972); Texts (1970, 1971, 1975, 1981)



Gerald Holton (1922 -)



F James Rutherford (1924 -)



Fletcher Watson (1912 – 1997)

(Harvard) Project Physics Course

- *"A national curriculum improvement project, which was funded by the U.S. Office of Education, the National Science Foundation"*
- *"Includes aspects of the philosophy and history of science that put the development of the major ideas of physics into a humanistic and social context"*

(Holton, Rutherford, & Watson 1971, p. 1)

Julius Robert von Mayer (1814–1878) was one of the first to realize that heat is a form of energy. He worked out the mechanical equivalent of heat.

Friedrich von Schelling (1775–1854)

One of the great successes of the *Naturphilosophie* was Oersted's discovery of the connection between electricity and magnetism (see Unit 4, Sec. 14.11). See also Unit 2 Epilogue.

Having said this, Joule got back to his work in the laboratory. was basically a practical man who had little time to speculate about a deeper philosophical meaning of his findings. But oth though using speculative arguments, were also concluding th the total amount of ener

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A scene from the Bayeux tapestry, which was embroidered about 1070. The bright comet of 1066 can be seen at the top of the figure. This comet was later identified as being Halley's comet. At the right, Harold, pretender to the throne of England, is warned that the comet is an ill omen. Later that year at the Battle of Hastings, Harold was defeated by William the Conqueror.

obtained predicted values reasonably close to the observed values available at that time. He even predicted some details of the motion which had not been noticed before.

Newton investigated the variations of gravity at different latitudes on the spinning and bulging earth. He noted differences in the rates at which pendulums swing at different latitudes. From these data, he derived an approximate shape for the earth.

In short, Newton created a whole new quantitative approach to the study of astronomical motion. Because some of his predicted variations had not been observed, improved instruments were built. These improved on the old observations which had been fitted together under the grand theory. Many new theoretical problems also clamored for attention. For example, what were the predicted and observed influences among the planets themselves upon their motions? Although the planets are small compared to the sun and are very far apart, their interactions are

2.8 | Galileo turns to an indirect test

Realizing that direct measurements involving a rapidly and freely falling body would not be accurate, Galileo decided to test an object that was moving less rapidly. He proposed a new hypothesis: *If a freely falling body has constant acceleration, then a perfectly round ball rolling down a perfectly smooth inclined plane will also have a constant, though smaller, acceleration.* Thus, Galileo claimed that if d/t^2 is constant for a body falling freely from rest, this ratio will also be constant, although smaller, for a ball rolling from rest down a straight inclined plane.

Here is how Salviati described Galileo's own experimental test in *Two New Sciences*:

A piece of wooden moulding or scantling, about 12 cubits long, half a cubit wide, and three finger-breadths thick, was taken; on its edge was cut a channel a little more than one finger in breadth; having made this groove very straight, smooth, and polished, and having lined it with parchment, also as smooth and polished as possible, we rolled along it a hard, smooth, and very round bronze ball. Having placed this board in a sloping position, by lifting one end some one or two cubits above the other, we rolled the ball, as I was just saying, along the channel, noting, in a manner presently to be described, the time required to make the descent. We repeated this experiment more than once in order to measure the time with an accuracy such that the deviation between two observations never exceeded one-tenth of a pulse beat. Having performed this operation and having assured ourselves of its reliability, we now rolled the ball only one-quarter of the length of the channel; and having measured the time of its descent, we found it precisely one-half of the former. Next we tried other distances, comparing the time for the whole length with that for the half, or with that for two-thirds, or three-fourths, or indeed for any fraction; in such experiments, repeated a full

Note the careful description of the experimental apparatus. Today an experimenter would add to his or her verbal description any detailed drawings, schematic layouts, or photographs needed to make it possible for other competent scientists to duplicate the experiment.

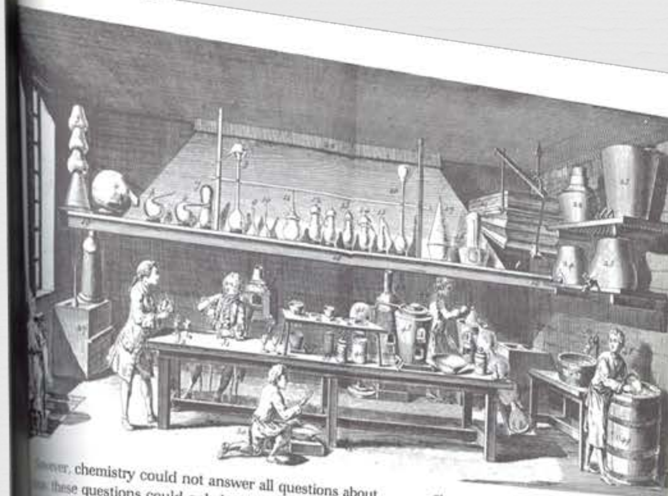
Experiment 1.5 in the *Handbook* is very similar to Galileo's test.

This picture, painted in 1841 by G. Bezzuoli, attempts to reconstruct an experiment Galileo is alleged to have made during his time as lecturer at Pisa. Off to the left and right are men of ill will: the blasé Prince Giovanni de Medici (Galileo had shown a dredging-machine invented by the prince to be unusable) and Galileo's scientific opponents. These were leading men of the universities; they are shown here bending over a book of Aristotle, in which it is written in black and white that bodies of unequal weight fall with different speeds. Galileo, the tallest figure left of center in the picture, is surrounded by a group of students and followers.

Thomas Alva Edison (1847-1931) was born at Milan, Ohio, and spent most of his boyhood at Port Huron, Michigan. His first love was chemistry, and to earn money for his chemical experiments, he set up his own business enterprises. Before he was fifteen, he ran two stores in Port Huron, one for periodicals and the other for vegetables; hired a newsboy to sell papers on the Grand Trunk Railway running between Port Huron and Detroit; published a weekly newspaper; and ran a chemical laboratory in the baggage car of the train. His financial empire was growing rapidly when, in 1862, a stick of phosphorus in his laboratory caught fire and destroyed part of the baggage car. As a result, his laboratory and newspaper equipment were evicted from the train, and he had to look for another base of operations.

It was not long before his bad luck with the phosphorus was offset by a piece of good luck: he was able to save the life of the son of the station agent by pulling him out of the path of an oncoming train. In gratitude, the station agent taught Edison the art of telegraphy, and thus began Edison's career in electricity.

At the right are shown two portraits of Edison. On the opposite page is a copy of the drawing that accompanied his patent on the incandescent lamp. The labeled parts are the carbon filament (a), thickened ends of filament (c), platinum wires (d), clamp (h), leading wires (x), copper wires (e), tube to vacuum pump (m).



Chemical laboratory of the eighteenth century.

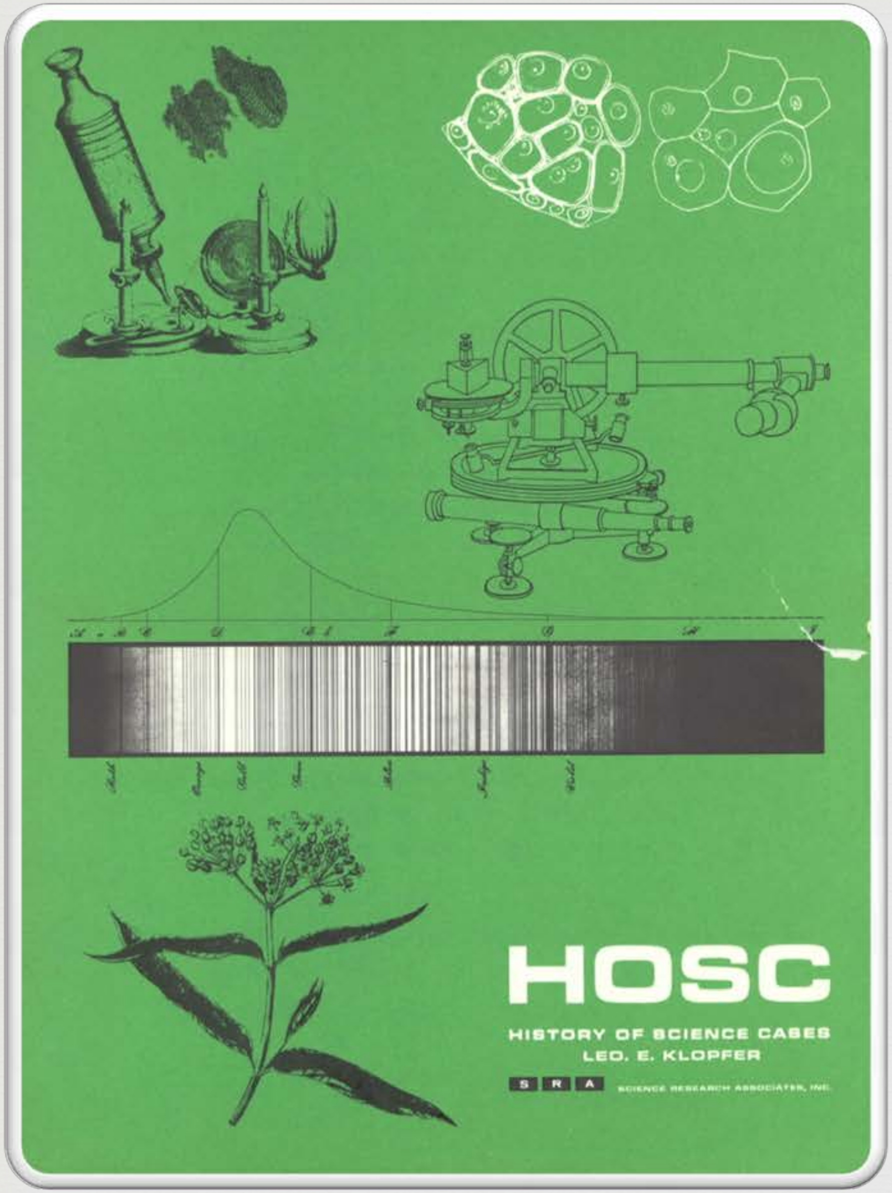
...ever, chemistry could not answer all questions about ... these questions could only be answered by physics. ... evidence accumulated in the nineteenth century and in ... years of the twentieth century made it possible to ... models not only for the atomic structure of matter but ... interior structure of the atom itself. This evidence will be ... in Chapters 18 and 19. You will see how this physical ... required a revision of the laws upon which all physical ... were based thus far, when these laws were applied ... phenomena.

...ter 20 deals with the triumphs of two theories belonging ... physics. These theories grew logically from the ... to understand the structure of the atom. At the same ... will begin to see that these new theories, too, are still ... in order to deal with the newest discoveries.

. . . but

- Research on the PPC impact featured rigorous large-scale quasi-experimental studies
- A total of 17 significant positive differences favoring PPC were identified
- However, *"no significant differences were found on the . . . Test on Understanding Science [TOUS]"*

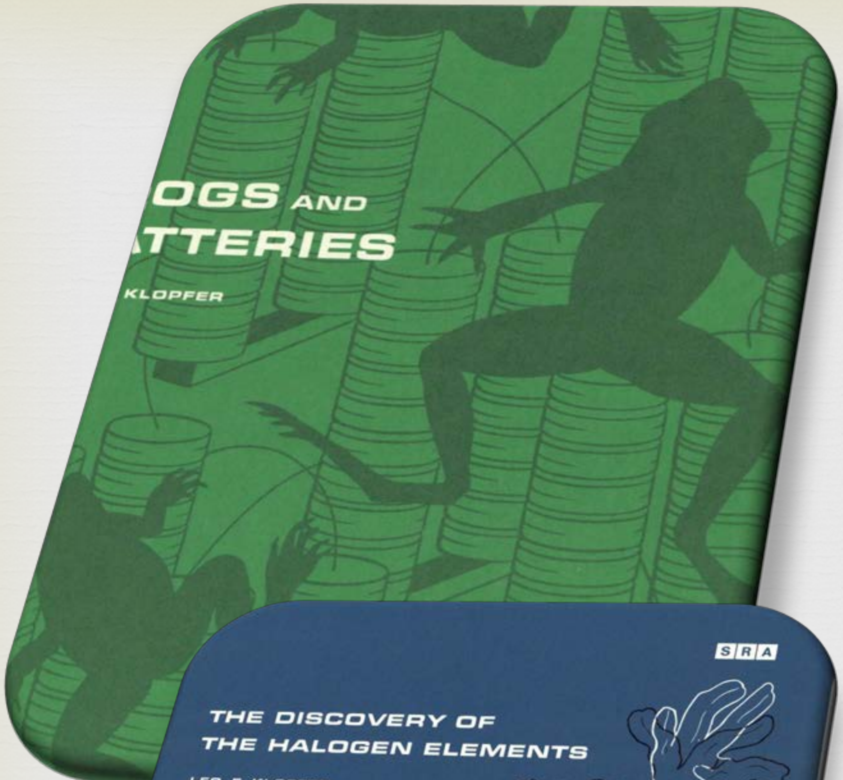
  (Welch, 1973, p. 374)

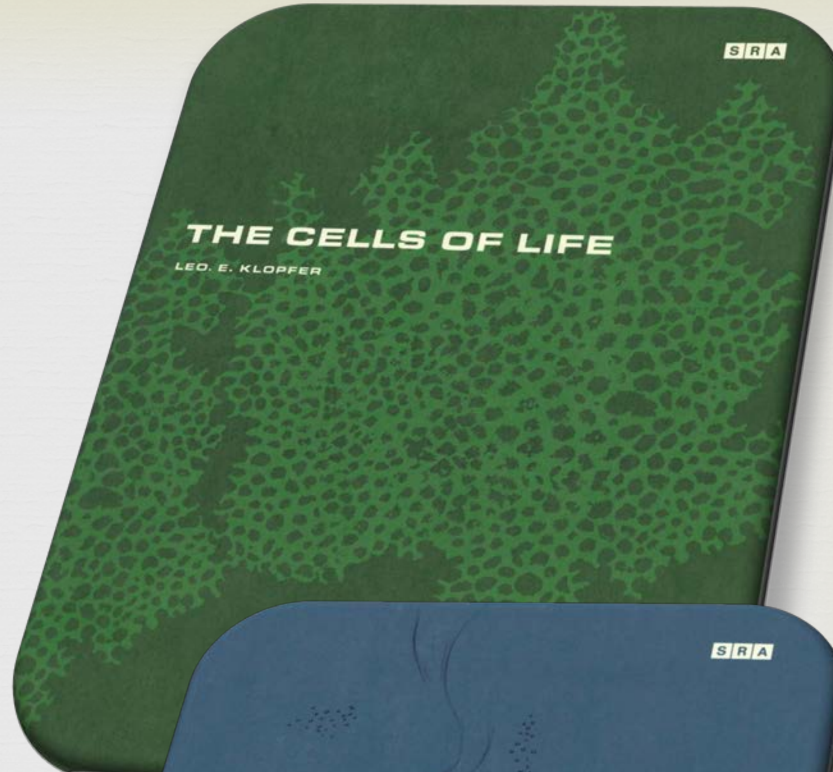


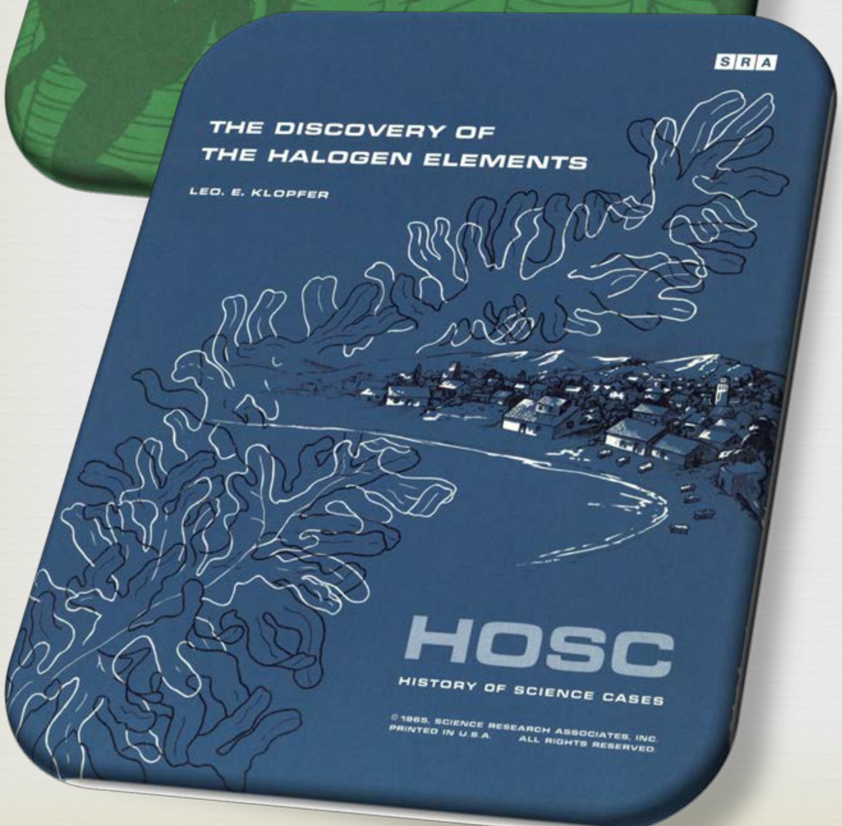
Leopold E. Klopfer's History of Science Cases (HOSC) for High Schools

"The inclusion of history of science in science teaching must be planned as carefully as the use of any other instructional materials"

(Klopfer, 1969, p. 92)


OGS AND
ATTERIES
KLOPFER


SRA
THE CELLS OF LIFE
LEO. E. KLOPFER


SRA
THE DISCOVERY OF
THE HALOGEN ELEMENTS
LEO. E. KLOPFER
HOSC
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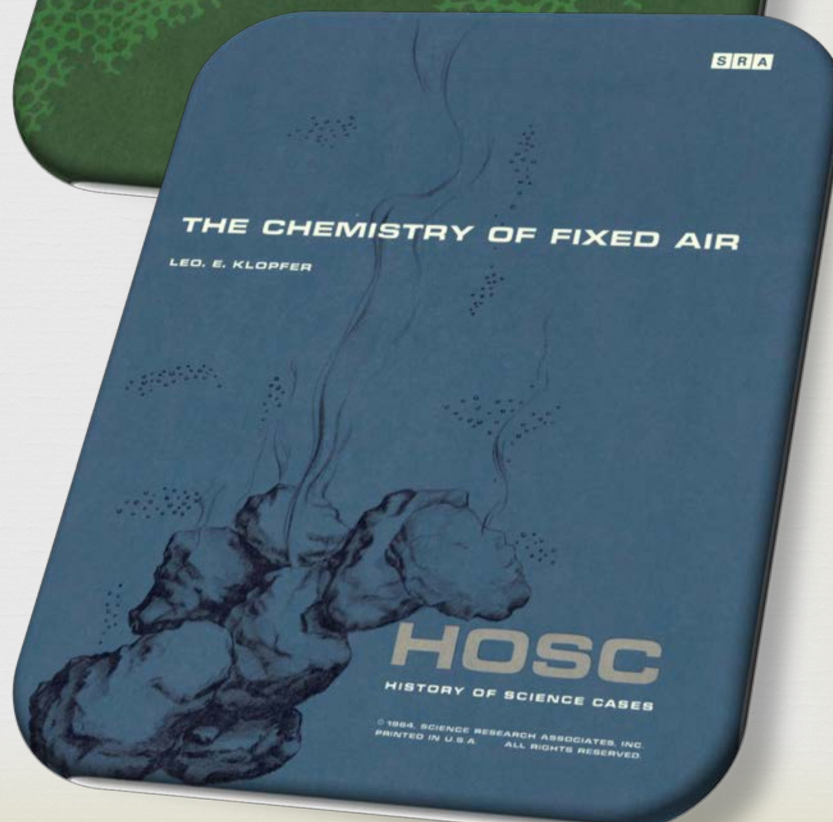
SRA
THE CHEMISTRY OF FIXED AIR
LEO. E. KLOPFER
HOSC
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TO THE TEACHER

In the present-day world it is essential that our students, the citizens of tomorrow, attain a clear and realistic understanding of the nature of the scientific enterprise, of the aims and processes of science, and of the people who are scientists. The HISTORY OF SCIENCE CASES (HOSC) have been prepared to provide you, the science teacher, with a means of guiding your students toward a better understanding of science and scientists.

Understanding Through Case Studies

In the HOSC unit that you are about to teach, this understanding is developed through a critical study of the major events leading to the formulation of the cell theory. As your students look over the shoulders of scientists engaged in creating science, they will witness (and participate in) the struggle to make microscopic observations, the difficulties and dangers involved in interpreting observations, and the rectification of erroneous notions through further research. They will follow the chain of reasoning, often intricate, that connects the broad statement of a theory with hypotheses susceptible to experimental tests, and they will be able to see the variety of personal characteristics that different scientists possess.

Although students studying *The Cells of Life* case will find that it has a good deal of science content, they should be made aware from the beginning that the case is not primarily a vehicle for learning science subject matter. They certainly ought to learn some biology from it (see Sections A and B under "Objectives for This Unit," found on page 10 of this guide), but the primary purpose of the HOSC units—to teach *about* science and scientists—should remain permanently in the foreground. (The particular ideas concerning science and scientists that are illustrated in *The Cells of Life* are listed in Section C of the objectives.)

In the final analysis the goal of the HOSC units is a greater sensitivity on the part of students to the manner in which scientists work and think. If, through the study of one or more cases, students become more alert to certain ideas about science and scientists, they will then look for these and other ideas in their further science readings and in their everyday sources of information. The ultimate goal is that an understanding of science and of scientists will become a functional part of the lives of the students who study these cases. Such an understanding will prove useful to all students in the years to come. For tomorrow's world will require that all citizens—not scientists alone—have an understanding of science.

Materials and Teaching Procedures

Although there is a variety of ways of presenting this case to your class, the suggestions offered in this guide have been found particularly effective in practice. Of course, the instructor can make whatever adaptations and extensions he believes will improve instruction in his class.

Basic to this case is the narrative that appears on the even-numbered pages of the student case booklet. Implicit in this narrative—which tells the story of the early development of the cell theory—are important ideas about science and scientists. In studying the narrative, the students usually will be able to discover these important ideas through thoughtful consideration of the marginal comments and questions to the left of the narrative.

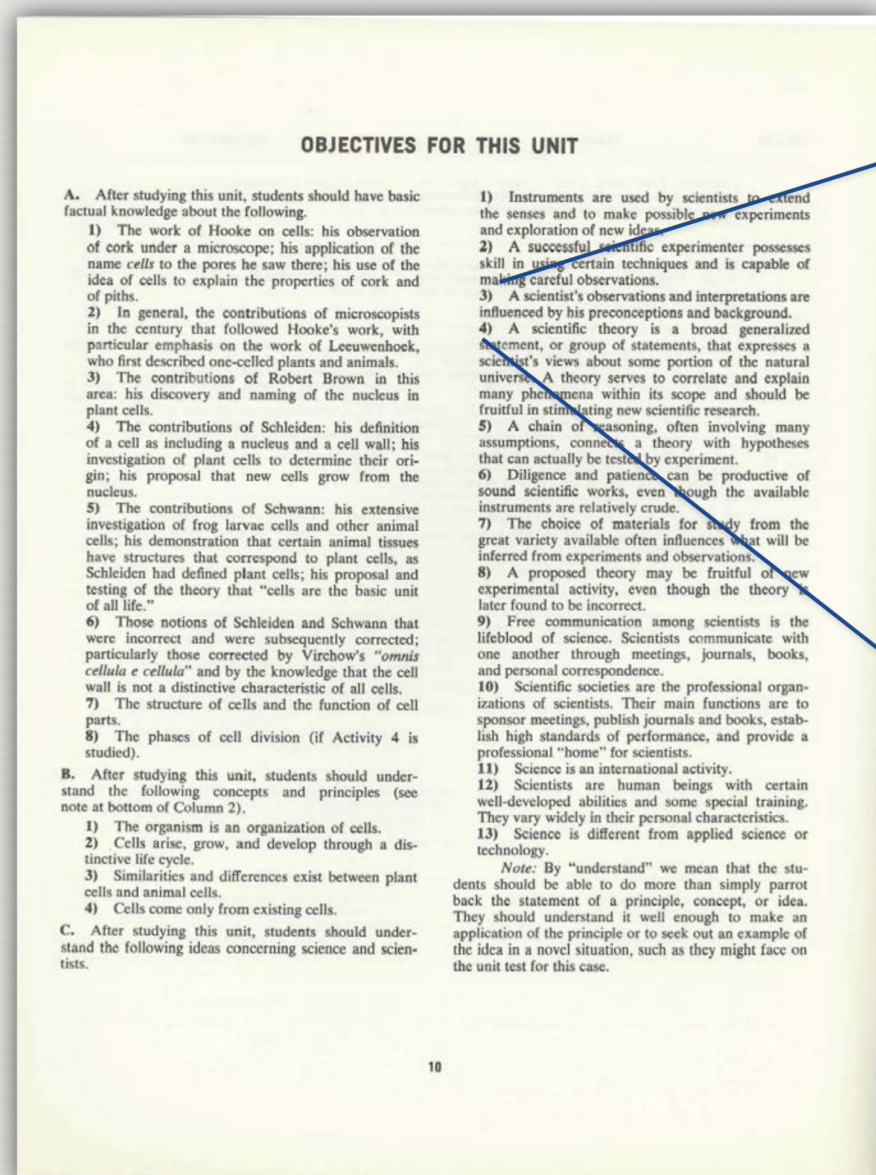
Some of the marginal comments lend themselves to individual and group assignments of supplementary reports based on suitable reference books. Marginal questions, in more detailed form, have been repeated on the page to the right of the narrative, and space has been provided there for students to write their answers. To assure consideration of the important points raised in these questions, it is good procedure to have students write out their answers as homework assignments. They should do so either directly in their case booklets or on separate sheets of paper. However, since the questions in the case booklet are not to be regarded as standard workbook questions, they should not be graded as workbook materials would be. Many of the questions do not have specific answers; and even when definite answers exist, they seldom are explicit in the text. Rather, the questions may be considered as starting points for the processes of discussion, of thinking through problems, of seeking out additional ideas and information, and of personal observation.

Some teachers may wish to give grades for day-to-day assignments of questions. This, of course, can be done. A check of a student's daily work, however, may better help the teacher evaluate the student's progress and his need for help in thinking, researching, and observing in new areas.

The experiments, which also appear on many right-hand pages of the case booklet, are an essential part of this HOSC unit. As many as possible of the suggested experiments, as well as other pertinent ones that the teacher may know of, should be carried out at appropriate points in this study of the case. The additional activities (pages 28–32) in the case booklet suggest appropriate extensions of certain points that are covered in the unit.

"Although students studying The Cells of Life case will find that it has a good deal of science content, they should be made aware from the beginning that the case is not primarily a vehicle for learning science subject matter . . . but the primary purpose of the HOSC units – to teach about science and scientists – should remain permanently in the foreground"

(Klopfer, 1964, p. 6)



OBJECTIVES FOR THIS UNIT

A. After studying this unit, students should have basic factual knowledge about the following.

1) The work of Hooke on cells: his observation of cork under a microscope; his application of the name *cells* to the pores he saw there; his use of the idea of cells to explain the properties of cork and of piths.

2) In general, the contributions of microscopists in the century that followed Hooke's work, with particular emphasis on the work of Leeuwenhoek, who first described one-celled plants and animals.

3) The contributions of Robert Brown in this area: his discovery and naming of the nucleus in plant cells.

4) The contributions of Schleiden: his definition of a cell as including a nucleus and a cell wall; his investigation of plant cells to determine their origin; his proposal that new cells grow from the nucleus.

5) The contributions of Schwann: his extensive investigation of frog larvae cells and other animal cells; his demonstration that certain animal tissues have structures that correspond to plant cells, as Schleiden had defined plant cells; his proposal and testing of the theory that "cells are the basic unit of all life."

6) Those notions of Schleiden and Schwann that were incorrect and were subsequently corrected; particularly those corrected by Virchow's *"omnis cellula e cellula"* and by the knowledge that the cell wall is not a distinctive characteristic of all cells.

7) The structure of cells and the function of cell parts.

8) The phases of cell division (if Activity 4 is studied).

B. After studying this unit, students should understand the following concepts and principles (see note at bottom of Column 2).

1) The organism is an organization of cells.

2) Cells arise, grow, and develop through a distinctive life cycle.

3) Similarities and differences exist between plant cells and animal cells.

4) Cells come only from existing cells.

C. After studying this unit, students should understand the following ideas concerning science and scientists.

1) Instruments are used by scientists to extend the senses and to make possible new experiments and exploration of new ideas.

2) A successful scientific experimenter possesses skill in using certain techniques and is capable of making careful observations.

3) A scientist's observations and interpretations are influenced by his preconceptions and background.

4) A scientific theory is a broad generalized statement, or group of statements, that expresses a scientist's views about some portion of the natural universe. A theory serves to correlate and explain many phenomena within its scope and should be fruitful in stimulating new scientific research.

5) A chain of reasoning, often involving many assumptions, connects a theory with hypotheses that can actually be tested by experiment.

6) Diligence and patience can be productive of sound scientific works, even though the available instruments are relatively crude.

7) The choice of materials for study from the great variety available often influences what will be inferred from experiments and observations.

8) A proposed theory may be fruitful of new experimental activity, even though the theory is later found to be incorrect.

9) Free communication among scientists is the lifeblood of science. Scientists communicate with one another through meetings, journals, books, and personal correspondence.

10) Scientific societies are the professional organizations of scientists. Their main functions are to sponsor meetings, publish journals and books, establish high standards of performance, and provide a professional "home" for scientists.

11) Science is an international activity.

12) Scientists are human beings with certain well-developed abilities and some special training. They vary widely in their personal characteristics.

13) Science is different from applied science or technology.

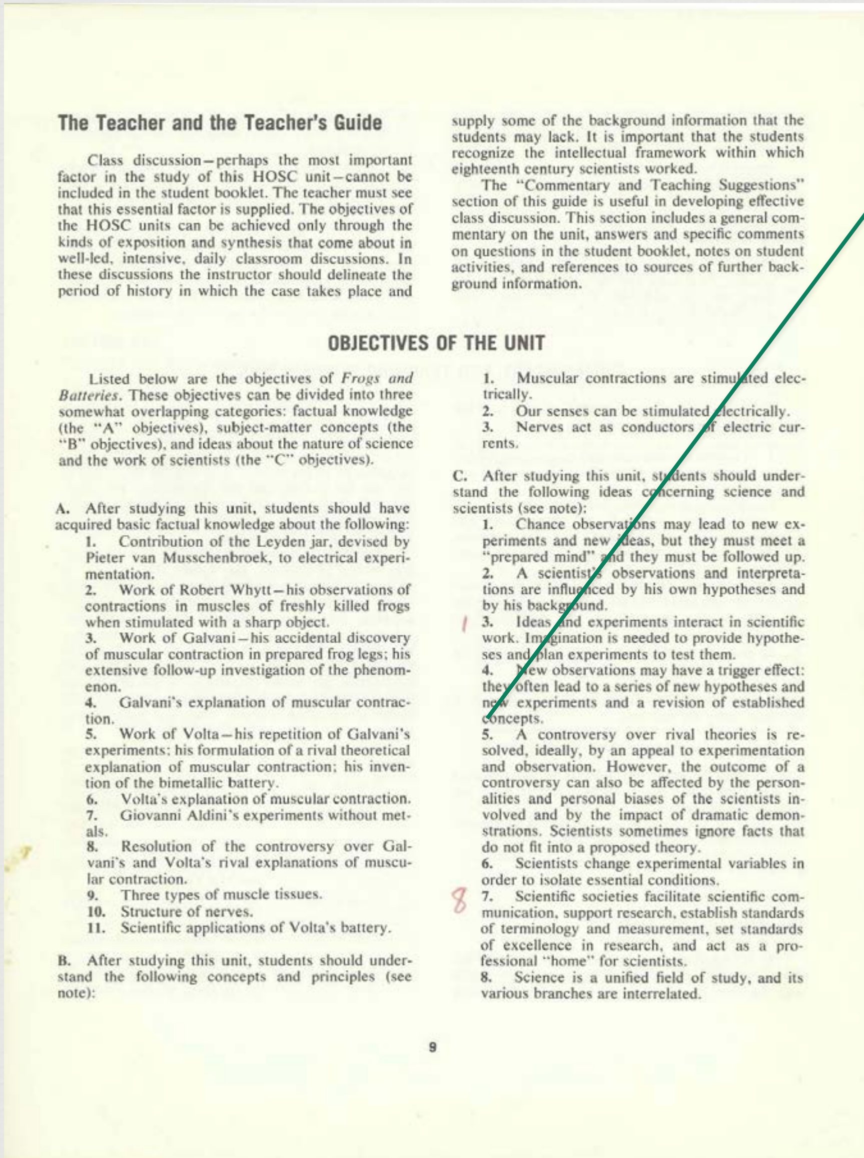
Note: By "understand" we mean that the students should be able to do more than simply parrot back the statement of a principle, concept, or idea. They should understand it well enough to make an application of the principle or to seek out an example of the idea in a novel situation, such as they might face on the unit test for this case.

10

"3) A scientist's observations and interpretations are influenced by his perceptions and background"

"4) A scientific theory . . . serves to correlate and explain many phenomena within its scope and should be fruitful in stimulating new scientific research"

(Klopfer, 1964, p. 10)



The Teacher and the Teacher's Guide

Class discussion—perhaps the most important factor in the study of this HOSC unit—cannot be included in the student booklet. The teacher must see that this essential factor is supplied. The objectives of the HOSC units can be achieved only through the kinds of exposition and synthesis that come about in well-led, intensive, daily classroom discussions. In these discussions the instructor should delineate the period of history in which the case takes place and supply some of the background information that the students may lack. It is important that the students recognize the intellectual framework within which eighteenth century scientists worked.

The "Commentary and Teaching Suggestions" section of this guide is useful in developing effective class discussion. This section includes a general commentary on the unit, answers and specific comments on questions in the student booklet, notes on student activities, and references to sources of further background information.

OBJECTIVES OF THE UNIT

Listed below are the objectives of *Frogs and Batteries*. These objectives can be divided into three somewhat overlapping categories: factual knowledge (the "A" objectives), subject-matter concepts (the "B" objectives), and ideas about the nature of science and the work of scientists (the "C" objectives).

A. After studying this unit, students should have acquired basic factual knowledge about the following:

1. Contribution of the Leyden jar, devised by Pieter van Musschenbroek, to electrical experimentation.
2. Work of Robert Whytt—his observations of contractions in muscles of freshly killed frogs when stimulated with a sharp object.
3. Work of Galvani—his accidental discovery of muscular contraction in prepared frog legs; his extensive follow-up investigation of the phenomenon.
4. Galvani's explanation of muscular contraction.
5. Work of Volta—his repetition of Galvani's experiments; his formulation of a rival theoretical explanation of muscular contraction; his invention of the bimetallic battery.
6. Volta's explanation of muscular contraction.
7. Giovanni Aldini's experiments without metals.
8. Resolution of the controversy over Galvani's and Volta's rival explanations of muscular contraction.
9. Three types of muscle tissues.
10. Structure of nerves.
11. Scientific applications of Volta's battery.

B. After studying this unit, students should understand the following concepts and principles (see note):

1. Muscular contractions are stimulated electrically.
2. Our senses can be stimulated electrically.
3. Nerves act as conductors of electric currents.

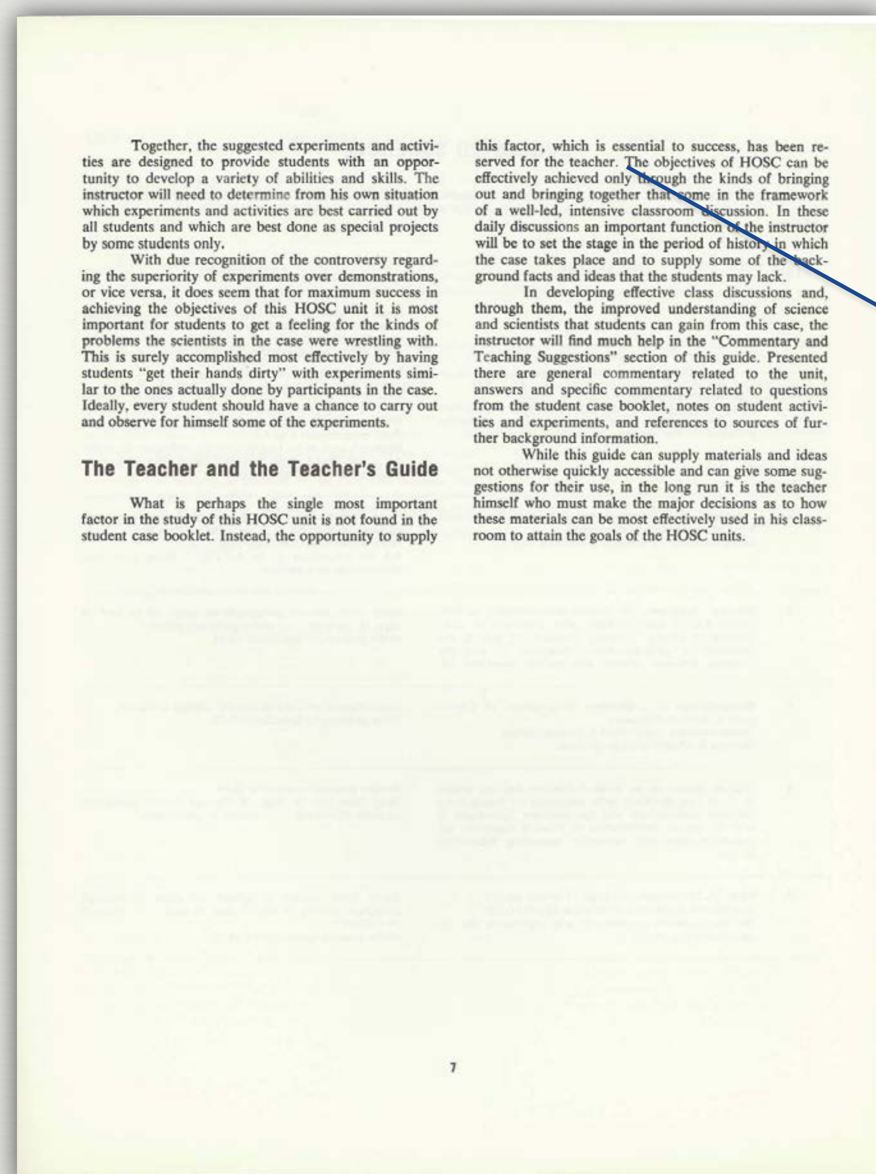
C. After studying this unit, students should understand the following ideas concerning science and scientists (see note):

1. Chance observations may lead to new experiments and new ideas, but they must meet a "prepared mind" and they must be followed up.
2. A scientist's observations and interpretations are influenced by his own hypotheses and by his background.
3. Ideas and experiments interact in scientific work. Imagination is needed to provide hypotheses and plan experiments to test them.
4. New observations may have a trigger effect: they often lead to a series of new hypotheses and new experiments and a revision of established concepts.
5. A controversy over rival theories is resolved, ideally, by an appeal to experimentation and observation. However, the outcome of a controversy can also be affected by the personalities and personal biases of the scientists involved and by the impact of dramatic demonstrations. Scientists sometimes ignore facts that do not fit into a proposed theory.
6. Scientists change experimental variables in order to isolate essential conditions.
7. Scientific societies facilitate scientific communication, support research, establish standards of terminology and measurement, set standards of excellence in research, and act as a professional "home" for scientists.
8. Science is a unified field of study, and its various branches are interrelated.

9

"5. A controversy over rival theories is resolved, ideally, by an appeal to experimentation. However, the outcome of a controversy can also be affected by the personalities and personal biases of the scientists involved . . . Scientists sometimes ignore facts that do not fit into a proposed theory"

(Klopfer 1966, p. 9)


Together, the suggested experiments and activities are designed to provide students with an opportunity to develop a variety of abilities and skills. The instructor will need to determine from his own situation which experiments and activities are best carried out by all students and which are best done as special projects by some students only.

With due recognition of the controversy regarding the superiority of experiments over demonstrations, or vice versa, it does seem that for maximum success in achieving the objectives of this HOSC unit it is most important for students to get a feeling for the kinds of problems the scientists in the case were wrestling with. This is surely accomplished most effectively by having students "get their hands dirty" with experiments similar to the ones actually done by participants in the case. Ideally, every student should have a chance to carry out and observe for himself some of the experiments.

The Teacher and the Teacher's Guide

What is perhaps the single most important factor in the study of this HOSC unit is not found in the student case booklet. Instead, the opportunity to supply this factor, which is essential to success, has been reserved for the teacher. The objectives of HOSC can be effectively achieved only through the kinds of bringing out and bringing together that come in the framework of a well-led, intensive classroom discussion. In these daily discussions an important function of the instructor will be to set the stage in the period of history in which the case takes place and to supply some of the background facts and ideas that the students may lack.

In developing effective class discussions and, through them, the improved understanding of science and scientists that students can gain from this case, the instructor will find much help in the "Commentary and Teaching Suggestions" section of this guide. Presented there are general commentary related to the unit, answers and specific commentary related to questions from the student case booklet, notes on student activities and experiments, and references to sources of further background information.

While this guide can supply materials and ideas not otherwise quickly accessible and can give some suggestions for their use, in the long run it is the teacher himself who must make the major decisions as to how these materials can be most effectively used in his classroom to attain the goals of the HOSC units.

"The objectives of HOSC can be effectively achieved only through the kinds of bringing out and bringing together that come in the framework of a well-led, intensive classroom discussion"

(Klopfer 1964a, p. 7)

Matthias Jakob Schleiden had little patience for lengthy, painstaking observations and plant classification. He irreverently referred to the valuable plant collections of the systematic botanists as "hay." To Schleiden, what was important in the study of botany was not the arranging of plants in neat groupings but rather the organizing of the science on the basis of a few fundamental principles. He plunged into this task with the zeal of a pioneer. For this reason, it is hardly surprising that he soon convinced himself that two of the fundamental principles he was seeking were found in his definition of the cell and his law of cell formation. *(Photo from The Bettmann Archive.)*

Again, observations do not speak for themselves.

As Schleiden continues his description of the growth of cells, we can see that he adds his own interpretations to the observations on almost every line. (There are at least three examples of this in the following paragraph. Can you spot them?)

> At the same time the young cell often shows very irregular extrusions [bulges] which is evidence that the growth is not effected from one point only. With further growth, however, the circumference becomes more regular, obviously due to internal pressure. The cytoblast is still included in the cell wall, in which place it remains throughout life. Only in those cells which are determined for higher development is it either dissolved in its place or expelled into the cell cavity as an organ without further use.

Schleiden formulates a law. What is a scientific law? (20)

Having made his observations, Schleiden generalized them into a law. In summary, he says:

> It is an absolute law that every cell takes its origin as a very small vesicle and grows only slowly to its defined size. The process of cell formation which I have just described . . . is that process which I was able to follow in most of the plants which I have studied. Yet many modifications of this development can be observed. In some plants the observation is difficult in parts or in all cells. Neverthless, the general law remains incontestable since analogy requires it, and since we fully understand the causes which sometimes prevent complete observation.

What does Schleiden mean by "analogy requires it"? (21)

Schleiden's work helped greatly to establish in the minds of botanists the idea that all plants are composed of cells. His notions concerning the formation of cells, which have just been described, were erroneous, as we shall see later. However, even in the imperfect form in which Schleiden presented it, the idea of the cellular structure of plants had an immediate and significant effect.

Is an incorrect idea of any value in science? (22)

"What is a scientific law? How can laws in science be established?" (p. 17)

"Are scientific ideas replaced very often?" (p. 24)

"Observations do not speak for themselves; they must be interpreted" (p. 14)

The HOSC were effective

- Pretest-posttest experimental study
- Random assignment of the HOSC treatment to 108 experimental and comparison classrooms
- Significant gains in the experimental students' NOS understandings as measured by the TOUS (Klopfer & Colley, 1963)

A final thought

- There is a lot to ask and try to answer about "How Can the HPS Contribute to Contemporary U.S. Science Teaching"
- But we already know quite a bit!
- The task before us is how to carefully situate ourselves for the future while making sure we seriously take into account what we have learned from the past

Thank You!

On context and teaching about NOS

- The search for a panacea for teaching about NOS continues!
- New prescriptions include scientific practices, argumentation, and socio-scientific issues, among others
- However, NOS is a *reflective* endeavor
- Thus, like with inquiry and HOS, these new contexts will not of themselves necessarily result in improved NOS understandings among learners

To teach about NOS, teach about NOS

- Effective NOS teaching
  - Clearly articulate NOS learning outcomes that are commensurate with context
  - Structure student learning experiences to embody (or, at least, illustrate) the target NOS learning outcomes
  - Provide learners with structured opportunities to reflect on their learning experiences from an epistemological lens
- Challenge with choosing and using contexts that are commensurate with target learning outcomes

Effective NOS instruction

- NOS instruction is most effective when it is an integrated and meaningful component of science teaching
- Approaches focused on add-ons and modules (e.g., NOS-specific or history of science units) are less likely to receive serious attention from teachers given their expansive science curricula

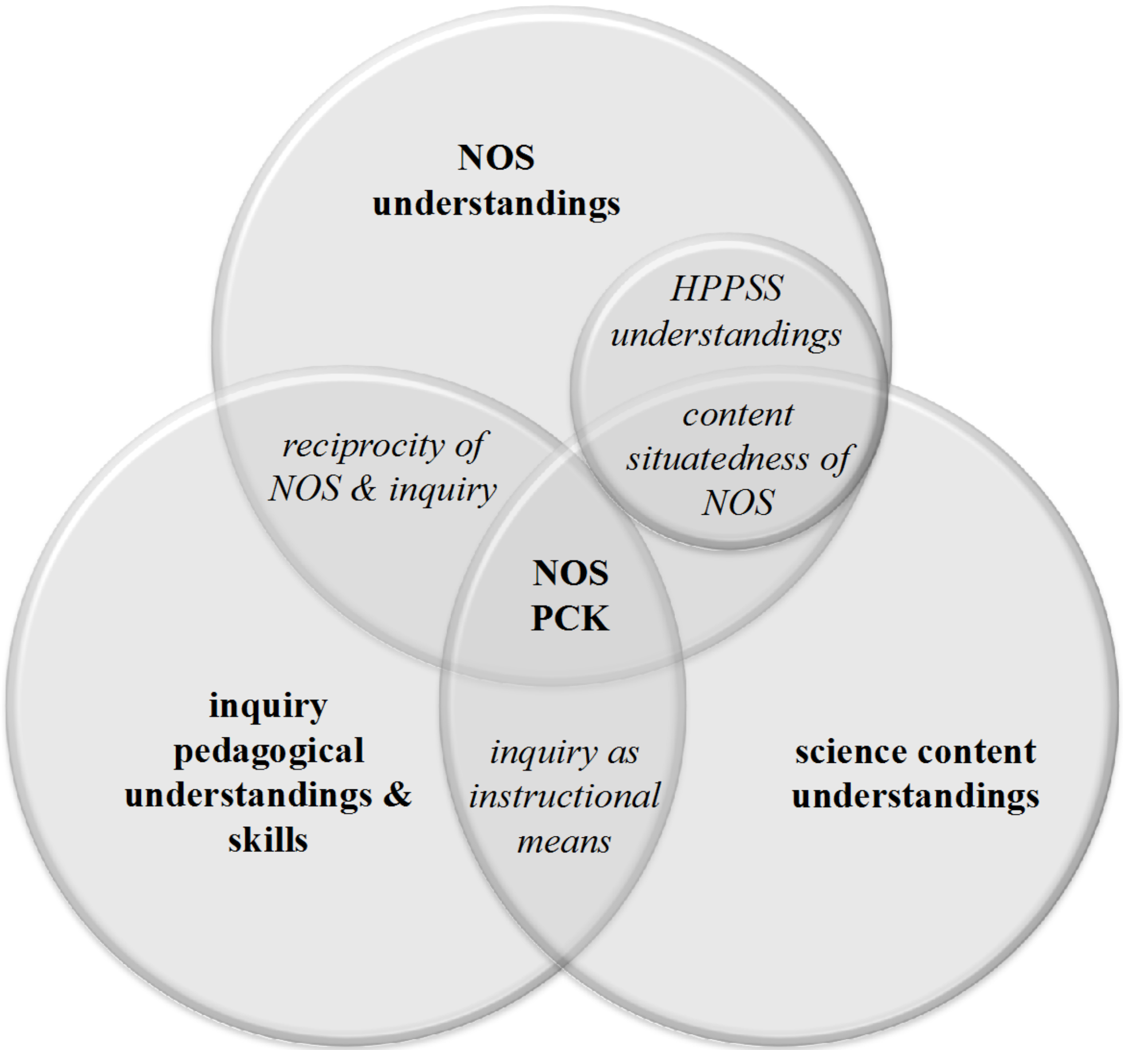


Figure 1. Teacher knowledge domains for teaching *with* and *about* NOS

Teaching *with* and *about* NOS

- Teaching *about* NOS is instruction aimed at helping learners develop informed epistemological understandings about the generation and validation of scientific knowledge, and the nature of the resultant knowledge
- Teaching *with* NOS entails designing and implementing science learning environments that take into consideration these robust epistemological understandings about the generation and validation of scientific knowledge

Teaching *with* and *about* NOS

- Turns the 'teaching about NOS with inquiry' coupling on its head
- Helps articulate and concretize Rutherford's (1964) claim that NOS understandings would result in improved ability among teachers to implement inquiry instruction

Abd-El-Khalick, F. (2012). Teaching *with* and *about* nature of science, and science teacher knowledge domains. *Science & Education*. DOI: 10.1007/s11191-012-9520-2