

Teaching Teachers the Conceptual History of Physics

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Introduction

Over the past seven years, we have taught the conceptual history of physics (CHOP) as part of courses aimed at the professional development of physics teachers. To do this, we developed pedagogical methods to teach the CHOP consistent with the accepted best practices of reform based teaching of science (Lawson et al., 2002). These practices rely on extensive student interaction in drawing conclusions and use of the instructor principally as a facilitator for classroom discussion.

The courses we teach are taken by (1) teachers teaching physics outside of their content field who need to earn certification in physics, (2) certified physics teachers who need graduate credit to maintain their license, and (3) physics teachers seeking to deepen their pedagogical content knowledge. The curriculum for each course is divided between physics content, readings from the physics education research literature, and readings from the conceptual history of physics. The courses are part of a project developed with funds from the State of Massachusetts for Improving the Teaching of Physics (ITOP).

We distinguish in our discussion here between the conceptual history of physics and the historical impact of discoveries in physics. It is the importance of this societal impact that is principally stressed in *Science for All Americans* (AAAS, 1990). While we firmly believe that the interplay between the sciences and the ideas that permeate society should be studied by all students, our emphasis is on understanding physics and the nature of science through the historical development of models in physics.

The sequence of courses we teach covers the physics content of a traditional three-semester sequence of undergraduate physics courses. This includes mechanics, fluids and thermodynamics, electricity and magnetism, waves, optics (geometric and physical), and modern physics (particles, quantum concepts, and special relativity). For the portion of the courses dedicated to the conceptual history of physics, participants read excerpts from original sources (e.g., Aristotle, Archimedes, Galileo, Huygens, Newton, Franklin, Faraday, Maxwell, Einstein), Shamos (1987), Matthews (1989), as well as secondary sources (e.g., Toulmin and Goodfield (1961; 1962), Matthews (1994), Holton (1978), Rhodes (1986)).

In what follows, we provide our rationale, discuss our pedagogical methods, provide explicit examples of our instructional methods, and report on the impact that the teaching of CHOP has had on the participating teachers.

Rationale

Teaching the conceptual history of physics supports many of the professional development objectives of our courses.

1. The CHOP offers teachers insights into many of the aspects of the nature of science (NOS). These include the NOS attributes listed by Lederman et al. (2002). The CHOP offers the opportunity to discuss aspects of the NOS that otherwise will not emerge in classroom inquiry.
2. Engaging teachers in the use of historical scientific models challenges them to think more deeply about the conceptual underpinnings of models. Study of earlier models further provides teachers with insights into what their students must do to accommodate the current scientific model, as well as insights into the commonsense models to which students intuitively adhere (Halloun and Hestenes, 1985; Clement, 1982; Driver, 1994).
3. Teachers teach the way they are taught (US DOE, 2000). If teachers are taught using the CHOP, it is more likely that discussions of historical models will make their way into classrooms.

The term *model* is used here in the broad sense of a theory that provides meaning to an observed pattern of phenomena (Halloun, 2007), as well as in the sense of being possibly interpreted as belonging to a Kuhnian paradigm adopted by a community and thereby apt to serve as a basis for inquiry and explanation (Kuhn, 1970).

Including CHOP in physics education follows a tradition established by many distinguished science educators (e.g., College of the University of Chicago (1949, 1950), Arons (1965), Conant and Nash (1957), Hobson (2003), Holton and Roller (1958), Holton and Brush (1985)). Matthews (1994) provides a review of the history of efforts to include the history of science in science education at the secondary level.

Instructional Methods for Inclusion of Historical Models

In the courses we offer, the instructors emphasize the use of reform instruction methods as defined by Lawson et al. (2002). The physics content portion of our courses is delivered with methods designed to maximize student interaction. To be consistent with the pedagogical methods employed for the physics content, and potentially make it easier for the teachers to

introduce the CHOP materials into their classrooms, we present the CHOP through interactive exercises requiring individual and group explorations of the material.

To present the CHOP in this manner, the approach we adopted is consistent with conceptual-change theory and research into how to help students accommodate new scientific concepts (Posner et al., 1982). We select primary readings that emphasize conflicts between successive scientific models.

Working with this perspective of the conceptual history of physics and reform pedagogy, we have developed worksheets for students that emphasize compare-and-contrast activities (Collins and Ferguson, 1993). Participants are asked compare and contrast different models of physics, or to role play and provide explanations for physical phenomena as might be argued by proponents of different models. Through the discussion that ensues they learn more about the theories' conceptual structures, domain of applicability, and shortcomings.

An Example of the Use of the CHOP from Thermodynamics

In the third course in our sequence, “Fluids and Thermodynamics”, participants learn about four different scientific models for heat, and its effect on materials. The participants read Wisner and Carey’s (1983) discussion of a 17th century model for the transmission of cold; a selection from Toulmin and Goodfield (1962) on caloric theory; and, a selection from Maxwell (1996) on physical kinetics. To these readings, we added an in-class introduction to Aristotle’s physics. Participants were familiar with Aristotle’s elements from their previous mechanics class (Toulmin and Goodfield, 1962). In class they are introduced to the four qualities of matter.

An example of the results of a class compare-and-contrast exercise for these different models of heat is provided in Table I. All but the first cell of Table I was completed in class by the students. (The first cell was provided as a finished example to guide completion of the other cells.) Each of the other three models (the Experimenters’ theory, the caloric theory, and the physical kinetic theory of Maxwell) was assigned to a group of two or three students. It was the responsibility of each group to report back to the class on how to reason with their assigned model to answer the questions posed for each row.

At first, the groups had difficulty answering the questions to fill out their assigned cells in the matrix. The instructor suggested that they answer what they take to be the relevant questions first. Eventually, each group completed their assignment. Some groups divided up the work

between a reader and a summarizer; in other groups, all read the text and recorded answers. The whole process took about half an hour.

When the groups were finished, the instructor projected the blank table on a screen. Working cell by cell, the entire class observed as the projected matrix was filled in and participated in discussion about the suggested responses from each of the groups.

The column on Aristotle was completed first based on participants' understanding of Aristotelian physics from previous classes, whole class discussion, and the instructor's facilitation.

The rest of the table was then filled out column by column, top to bottom. At each box, the participants were asked whether it constituted an important change from the corresponding cell in the prior adjacent column. Each column was completed with participants contributing and the facilitator editing the entries in real time. When disagreements arose (e.g., about whether or not Lavoisier's caloric has a mass), precise passages from the texts were consulted. Completing the matrix took another 30 minutes.

	Aristotle	Experimenters	Caloric Theory (Lavoisier)	Physical Kinetics (Maxwell)
What are the fundamental qualities involved?	<i>- 4 elements: air, fire, earth, water (plus ether)</i> <i>- 4 qualities: hot, cold, wet, dry</i>	Hot and cold particles that have a force	Fluid that carries heat and energy with it: caloric. Type of matter, but massless.	Massive molecules have speeds → kinetic energy (= temperature)
What data were collected by the researchers?	Ratios of qualities & quantities	Measured expansion of bodies, phase change	Measure of mass, temperature, expansion of bodies	Pressure, mass, volume, temperature
What is conserved?	Things tend to go to rest / equilibrium (natural state)	Not a problem for them	Matter	Energy and mass
What was the cause of the change in state or temperature?	Addition of elements with different qualities (by violent change)	Force applied by hot / cold particles	Movement of caloric from hot to cold bodies	Change in particles' speed
What experimental evidence supports this theory?	Immediate observation	Expansion experiments with large reservoir sources	Explains thermal equilibrium	Boyle's law, Joule's mechanical equivalence of heat
Can you pose an experiment that falsifies the theory?	Exothermic reaction	2 masses w/ diff temp. come to thermal equilibrium.	Increase in pressure → increase in temp with no change in 'caloric'	No absolute zero

Table I Models of Heat

Participants were asked the question: "Using the different models of hot and cold that we have encountered, explain how each would be applied to explain the boiling of water?" The cell contents shown were the product of whole class discussion with the exception of the first cell where the italicized content was provided at the outset.

	Aristotle	The Scholastics (e.g., Buridan, Oresme)	Galileo	Newton
Description of Kinematics [Describing an object in motion]	Natural Change vs. Violent Change Observed that Celestial motion is circular and terrestrial is linear Distance proportional to speed	<i>Concepts of time, distance, speed, and acceleration. Circular motion natural. Acceleration is change of speed with respect to distance.</i>	Acceleration is key; things fall at constant acceleration; every motion is circular; things can move without stopping	Introduced velocity rather than speed. Change in direction requires an acceleration: Vectors
Description of Dynamics [Why is an object in motion: Involves forces]	<i>Effectively $F=mv$. Natural positions for elements results in their motion. Objects move with applied force. Motion of unpowered projectiles is poorly explained.</i>	God initiated motion ** Impetus keeps things going; degrades over time due to outside forces	Balancing forces in statics; Acceleration as adding speed? “Why” doesn’t matter!	Laws of Motion
Use of Mathematics	Proportionality for like quantities No mixed units Not very useful	Logic Choppers to interpret Aristotle Define new quantities mixing units. [Graphical/geometrical Representation]	<i>Proportionality arguments and graphical representations using Euclidean geometric arguments. Idealizes physical observations to fit mathematical results.</i>	Integral Calculus
Source of Supporting Empirical Data	Observed the world around him. The natural world	Aristotle’s observations	Compiled previous works with experiments	<i>Kepler’s observations and Laws. Galileo’s data.</i>
Texts	Physics	Journals; not collected in one place	Dialogs	Principia: logical proof,
Evolution or Revolution: Reasons for New Descriptions and Models	** Evolution – compared to what was going on around him; compiled previous knowledge [Revolution against Plato]	<i>Inconsistencies and incompleteness in Aristotelian description of motion and dynamics.</i>	Revolution: used time as the independent variable; Revolted against previous scholars	** Revolution – introduces new mathematics to explain motion; logical proof for dynamics Evolution from Galilean ideas

Table II: Kinematics and Dynamics Matrix

Legend: Bold for headings. Italics for initial entries prior to student work. ** indicates significant discussion. [] indicates instructor’s contribution.

Two months later, Table I was revisited with the participants. They were asked about how they had completed the table. After having briefly responded to this question, the participants chose to discuss its relevance instead. They informed us that this compare-and-contrast exercise is very useful for them to better understand the historical evolution of the scientific understanding of the phenomena considered. They reported that it adds interest to the reading of the texts; without this comparison, the series of texts appear unconnected. The difficulty in the interpretation of the language used in primary sources makes their effective use hard in a physics class. Yet, this table exercise seems to clarify the interpretation of such language for the students.

More generally, several participants volunteered that studying physics through its conceptual development helped them better identify sources of misconceptions their students may have. For example, one teacher related that when her students thought of cold and heat as two distinct substances, the teacher was able to clearly discern the misconception, and tell the students that “there once was a whole school of thought that held the same view.” Instead of bluntly telling the students that they were wrong, the teacher was able to lay out counter-examples. Among the session’s participants, there was a strong consensus regarding the value of the CHOP in helping them identify how students were reasoning (discussed below).

An Example from Dynamics

In Table II we provide another example of a class interactive completion of a compare-and-contrast exercise. In this case, the challenge is not to model a specific physical phenomenon, but rather to contrast broadly different models of dynamics. Again, the exercise was conducted in class after assigned readings from the CHOP. For Aristotle and the Scholastics, selections were assigned from *The Fabric of the Heavens* (Toulmin and Goodfield, 1961); for Galileo, the selections were from *Dialogues Concerning Two New Sciences* (Galileo, 2002); and, for Newton the selections were from *Principia* (Newton, 2002).

Students appear to use models of dynamics akin to those of Aristotle or the Scholastics. Such phenomenon has been documented by multiple authors (Halloun and Hestenes, 1985; Clement, 1982). Discussing the conceptual development of dynamics prepares the course participants for their readings from the physics education research (PER) literature. In turn, reading PER articles alerts the participants to the pedagogical utility of studying the CHOP materials.

The matrix in Table II is completed in the first course in our sequence. For this reason, we completed several cells for the participants to help them understand what was expected of them.

Other Uses of the CHOP

In other classes we use CHOP materials to stimulate inquiry and discussion through the reenactment of crucial scientific experiments. For example, we examine Galileo's marble on a ramp experiment from which he found that there is uniform vertical acceleration for an object near the surface of the Earth. For this instruction, we use an interactive classroom exercise with a water clock similar to that described by Fowler (2003).

Questions of scientific idealization, data selection and experiment reporting are explored using Matthews' (1994) example of idealization provided by Galileo's treatment of the pendulum in *Dialogues Concerning Two New Sciences* (2002), and Holton's essay on the conflict between Millikan and Ehrenhaft on the charge of the electron (Holton, 1978). Both historical cases result in very active discussion by our teacher participants.

CHOP and the teacher participants' teaching methods.

The teachers report improvement in the understanding of their students' conceptual learning processes. They also report that they think about the history of physics much more frequently after taking our courses (see Figures 1-6).

An example of the impact of the CHOP on classroom instruction is the report of one teacher who had her students study historical models of motion, similar to what is done in our course. Her students worked in groups and prepared reports to the class about Aristotle, the Scholastics, Galileo, and Newton. When she reported to us on the assessment of her students, she commented:

Many of my high school students are stuck in the Middle Ages with some sort of an impetus force that keeps things going...For example, most students recognized that the car hitting a barrier and stopping will not cause the passenger in the car to stop, and the passenger will continue moving unless restrained by a seatbelt, or until a collision with the dashboard or windshield or road ensues. So far, so good. But then some students elaborated about the next step as the force that moved the person toward the dashboard had to be countered.

Other examples of the impact of the CHOP on classroom teaching are provided by participants' response to an open-ended question on a survey that asked how they used the CHOP in their teaching. Some of the responses included:

- Showing students that their misconceptions are similar to the misconceptions of people like Aristotle.
- Transitions or paradigm shifts such as Aristotle to Galileo, or Newton to Einstein.



Fig. 1: Rate your knowledge of the history of physics (*before* ITOP, n =74)

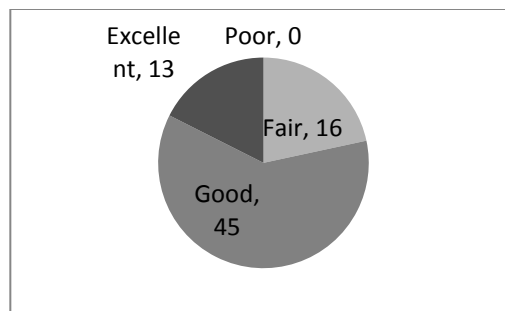


Fig. 2: Rate your knowledge of the history of physics (*after* ITOP, n =74)

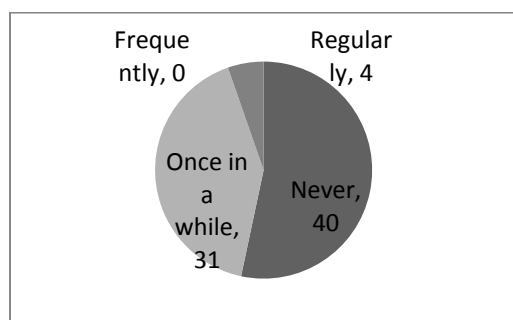


Fig. 3: Your use of the history of physics to better understand student learning (*before* ITOP, n=75)

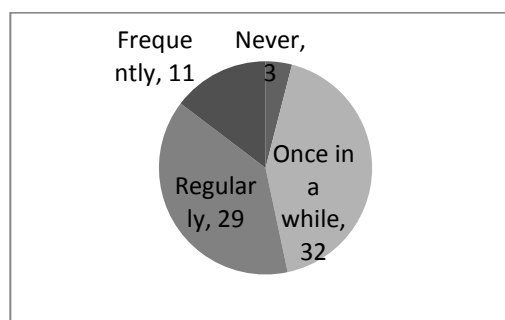


Fig. 4: Your use of the history of physics to better understand student learning (*after* ITOP, n=75)

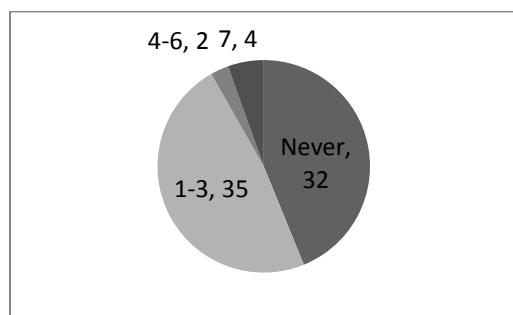


Fig. 5: The frequency (times per month) with which you think about the history of physics (*before* ITOP, n=74)

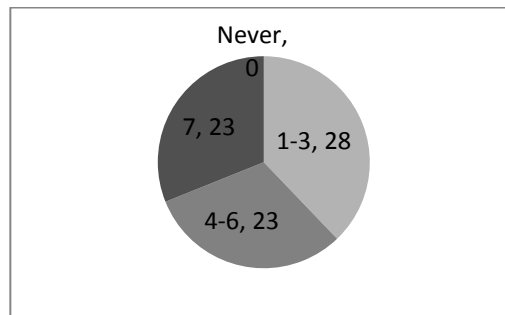


Fig. 6: The frequency (times per month) with which you think about the history of physics (*after* ITOP, n=74)

- “When introducing motion, I discuss the Aristotelian paradigm as a common sense view. Objects in motion do appear to act that way. The Newtonian paradigm now has a background to emerge from so that its characteristics can be more clearly seen and understood.”
- In introducing Newton's three laws of motion, we look at the Aristotelian paradigm of exploring physical phenomena observationally and the experimental/theoretical approach of Galileo.
- Development of concept of light: Huygens, Newton, Maxwell, Einstein; concept of acceleration: Aristotle, Galileo.
- Excerpts of Franklin's writings to explore static electricity.
- “I used the examples from the program in teaching thermodynamics to my AP Chemistry students. I do not currently teach physics. I also used conceptual history examples in gas laws (concepts of force) and in quantum mechanics. This part of the course has been immensely valuable to my teaching.”

Conclusion

We have reported on our development of a collection of exercises to use for interactive instruction in the conceptual history of physics. These exercises focus on the nature of models, and the nature of science. There are many other strategies for instruction in the history of physics (for instance, see Stinner et al., 2003; Seroglou et al., 1998). We have chosen to develop a pedagogical strategy of compare-and-contrast activities from which teachers can generalize to design their own inquiry-based activities that exploit the CHOP for improved classroom instruction.

Based on the surveys we have conducted, there is encouraging evidence that teachers who are instructed this way subsequently find it useful to use their knowledge of the CHOP in their classrooms. They report this both through their claim to use of the CHOP for classroom activities and in claiming that they use the CHOP to better understand how their students are learning after their participation in the program.

Measuring impact of new pedagogical strategies on teachers' classroom behavior is difficult. Much of the pedagogical content knowledge (PCK) that teachers accumulate and rely upon remains hidden during any given class. Uncovering the extent to which the CHOP instruction has

been integrated into their PCK remains a research question for us. We are continuing our investigations to determine more explicitly the impact of CHOP instruction on teachers' practice through classroom observations and case studies.

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