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AUTHOR Loving, Cathleen
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The model developed for use with science teachers--called the Scientific Theory Profile--consists of placing three well-known philosophers of science on a grid, with the x-axis being their methods for judging theories (rational vs. natural) and the y-axis being their views on scientific theories representing the Truth versus mere models of what works best (realism vs. anti-realism). The assumption is that individuals have different degrees of commitment to these views and seeing this range of views would help science teachers develop a balanced philosophy of science. The philosophers selected for detailed analysis who form the "keystone" positions on the Profile are Thomas Kuhn, Carl Hempel, and Sir Karl Popper. Nine other contemporary philosophers, all influenced by the three originals, are included in brief analyses, with their positions relative to the keystones. Analyses resulted in placement of four Natural Anti-realists, three Rational Anti-realists, four Rational Realists, and one Natural Realist. The Natural Realist, Ronald Giere offers a cognitive approach to explaining theory judgment, which appears particularly useful to science teachers. The Profile then forms the basis for a course in philosophy of science for science teachers, with some objectives and activities suggested. (Author)

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THE SCIENTIFIC THEORY PROFILE: A PHILOSOPHY OF SCIENCE MODEL FOR SCIENCE TEACHERS

Cathleen Loving, Associate Professor
Departments of Biology and Curriculum, Teaching and Educational Technology
California State University, Fresno

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ABSTRACT

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The Scientific Theory Profile: A Philosophy of Science Model for Science Teachers

INTRODUCTION

While Hurd (1990) calls for a "recontextualization of the science curriculum .. with subject matter selected to emphasize human development, human affairs, and the welfare of society in contrast to the "structure of science," he recognizes that "emerging perspectives in the educational reform movement suggest there is a need for serious study of **a) the philosophy of modern science and technology**, b) the sociology of knowledge, c) the cognitive sciences, and d) the culture of today's schools (p.414)." This suggests that as we move into new areas of curricular emphases, away from fact-laden, discipline-bound science teaching, and into richer, conceptual understanding, the decisions on what to teach and what to eliminate require a deeper understanding of what science is and is not.

Others recognizing the value of study in modern philosophy of science call for working towards a more philosophically valid curriculum (Hodson, 1988), eliminating the positivist, non-developmental model of how science is done and how theories are born (Duschl, 1988; 1990), and learning to value the special role sound scientific explanations play in good science (1988, Horwood). As we enter the first era of major curriculum revision in science education since the 1960's, it is important not to repeat the mistakes made when a mutual exclusivity, as Duschl (1985) calls it, existed between what science education promoted in its programs and what was being written in the revolution taking place amongst philosophers, historians, and sociologists of science.

Some of the most exciting and potentially powerful changes taking place today in science education have to do with new directions in curricula for both students and teachers. Calls for better philosophical perspectives are coming from diverse places. These perspectives are explicitly called for by the Project 30 team (Fallon & Murray, 1989) in describing one of the ways science teachers should be educated. They suggest a student major in the philosophy of her subject. Early research by Kimball (1967) supports this view. He found philosophy majors scored significantly higher on the Nature of Science Scale (NOSS) than did science majors, especially on questions about methodology. Both Project 2061 (AAAS, 1989) at the national level and the new California Science Framework for K-12 (Cal. Dept of Education, 1990) at the state level call for a more thematic, integrated approach to teaching science, allowing in-depth approaches to important issues. This emphasis requires teachers writing and teaching new programs to understand the extent integration of the various sciences is possible. Planning these integrated courses can be enhanced by knowing the **unique aspects** philosophers have identified which separate the "paradigm" of say, the molecular biologist from that of the nuclear physicist, in terms of such things as what counts as good data or how fruitful are the reigning theories. Likewise, the **similarities** of most mature sciences, as identified by philosophers, are important for teachers to identify. Rather than the lock-step, positivist Scientific Method often portrayed in classes across America, a dynamic framework within which acceptable modes for asking questions, for holding firm to preconceived theories, and for devising new explanations can be identified.

At the undergraduate level, research is supporting a philosophical/developmental approach to science. In the Liberal Art of Science (1990), a recent AAAS study, courses for both science majors and nonmajors with a philosophical/developmental emphasis are promoted and

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highlighted. Tobias (1990) found the mature, well-educated students enrolled in general undergraduate physics and chemistry courses--as part of the team in an ethnographic study--longing to hear from their professors about how methods came about and how the discipline decided standards.

Students need to be given an accurate picture of what science is and is not, of its relation to technology and of each to society, of good versus poor science, of what it took to get where we are today, and of the continuous struggle in all disciplines to come up with better explanations about natural phenomena. "Final form" science, as Richard Duschl has repeatedly called it, is dangerous, is pervasive, and is turning young people off to science as something they want to know more about, to make decisions regarding, or to be a part of their career. A philosophically alive course for science teachers could make a difference in these trends.

Two significant contributions are from Aikenhead (1986), who combines historical case studies with current epistemological models to support an STS approach, and Duschl (1990), who offers six epistemological models to be used with science teachers for better decision-making regarding how to present scientific theories and what is most important to teach. This study may complement and enhance their work by providing an overall model and an additional context from which to look at current philosophers' views regarding scientific theories.

PURPOSE

This study provides a model to illuminate and relate various 20th Century philosophical perspectives on key questions about the nature of scientific theories and, therefore, aspects of the structure and development of postmodern science. **The research questions are the following: 1)** What perspectives in philosophy of science combine the best elements of descriptive accuracy with normative standards to be most useful to science teachers in developing their own views on the nature of current science? 2) Can a schema or model be drawn to aid in indicating various noteworthy positions on important questions related to scientific theories? 3) What practical applications of this model can be developed for use with preservice or inservice science teachers, in hopes that they will portray science with deeper understanding and sensitivity.

DESIGN AND PROCEDURES

The background for the development of the model includes not only a literature search in both philosophy of science and science education, but a questionnaire which was sent to seventeen active NARST members whose institutions have undergraduate programs for science teachers and/or graduate science education programs. The six questions were designed to reveal the extent to which any philosophy of science studies were incorporated into required courses. Responses to the questions prompted examination of ten recent methods texts (six elementary/middle school and four middle/high school), to detemine whether reasonably complete portrayals of postmodern science were included, since the methods course was most frequently cited as the place where philosophy of science was at least mentioned.

Next, after extensive analyses of the relevant literature, a model was developed for preservice or inservice science teachers which illustrates the current range of views in philosophy of science regarding two important questions about the nature of scientific theories. Taking a cue from a model mentioned as a possibility by Ronald Giere (1988, p. 8) and adapting it to show the spectrum of views on theories, the Scientific Theory Profile was developed. It consists of an x, y-axis grid whose placement points represent leading philosophers' poisitions regarding:

1) whether theories are judged rationally, naturally (with significant psychological, historical or sociological dimensions), or in some combination [the x-axis]; and

2) whether reigning theories represent a truth and reality (realist), mere models of what works best (anti-realist), or somewhere in between [the y-axis].

There are powerful arguments involving these two questions which illuminate views on the very essence of what science is and is not.

Beginning with three philosophers of science in the 20th century who could be called the "keystones," Thomas Kuhn, Sir Karl Popper, and Carl Hempel, writings were analyzed and points were placed on the grid for twelve contemporary philosophers (some like Kuhn and Gerald Holton are also historians). All four quadrants have at least one representative, three quadrants have at least three. There are no numerical values assigned to the grid positions. Placements are relative to the positions chosen for the three keystone philosophers and also in relation to others in one's own quadrant. The four quadrants are the following:

QUADRANT A - Natural Anti-realist, QUADRANT B - Rational Anti-realist, QUADRANT C - Rational Realist, QUADRANT D - Natural Realist.

Finally, some goals, objectives, and activities are suggested for practical use of the Scientific Theory Profile in a course for science teachers.

RESULTS

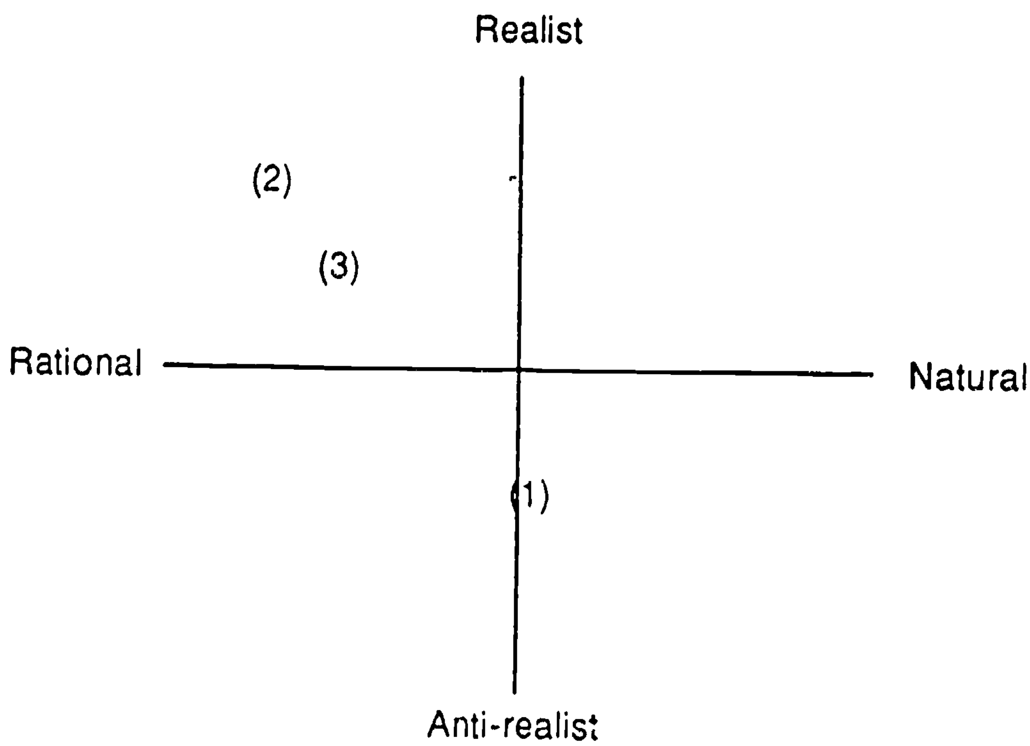
The seventeen-institution survey reveals an overall lack of attention to any philosophy of science emphasis, with one or two exceptions; and the methods text evaluation indicates all but one of the ten examined have somewhat inaccurate or incomplete portrayals of postmodern science (see Loving, 1990 for detailed analysis). Responses to two questions in the survey which are representative show that 13% of undergraduate science education majors and 19% of graduate students have a philosophy of science course in their degree plan, and 0% of the undergraduates and 25% of graduate students "always" examine texts and curricula for the philosophical perspective of the authors.

Analysis of the twelve philosophers reveals that virtually all value good scientific theories as both powerful and the best explanations that science has to offer, yet distinct positions appear on the Profile as to how those theories are judged and represented. The three keystone philosophers are shown in Figure 1. The nine others are placed around them (see Figure 2), as their writings reveal their being affected by the keystones, reacting to them, and developing alternative positions--thus, their unique place on the Profile. For the sake of brevity, only Gerald Holton, Larry Laudan and Ronald Giere, in addition to the keystone philosophers, are highlighted here. The others are mentioned briefly. Their positions are each unique, well known and worthy of study. For more detailed anlaysis of the nine, see Loving (1990).

THE KEYSTONE PHILOSOPHERS

A brief description of the keystone philosophers' position on the Profile follows. For detailed analyses see Loving (1990).

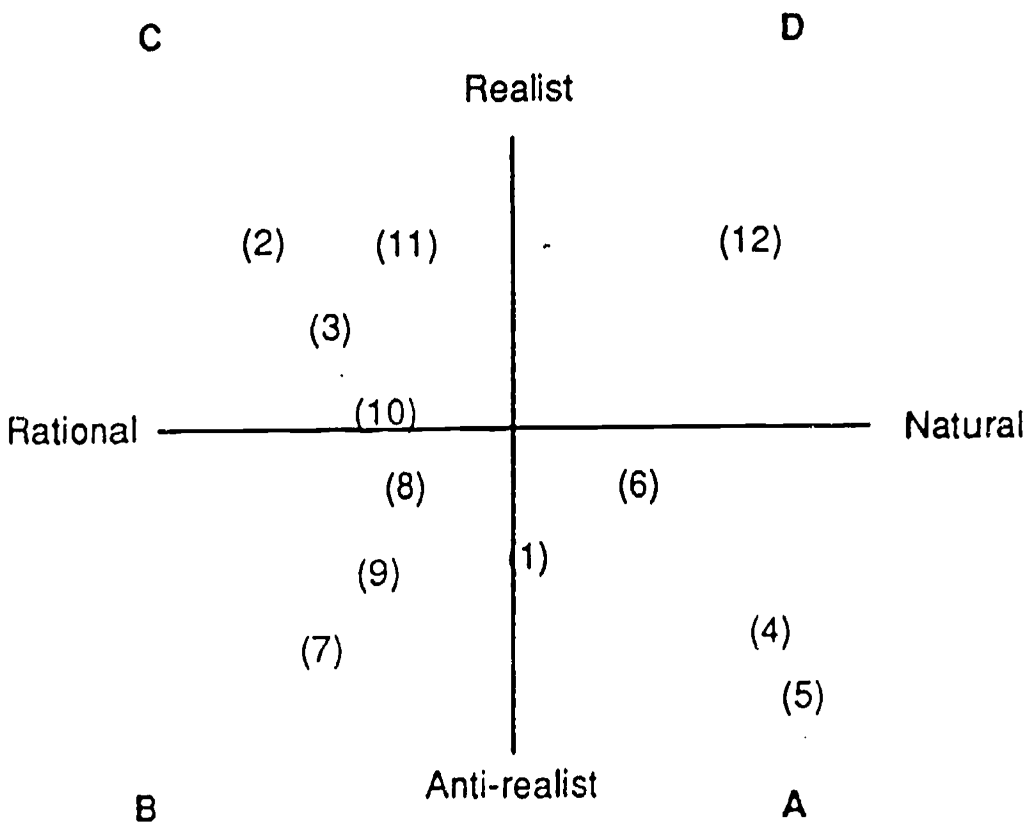
Thomas Kuhn's (1970b; Position 1) Structure of Scientific Revolutions has been described even by one whose views differ considerably as the "single most influential work on the philosophy of science that has been or will be written in this century" (Glymour, 1980, pg. 94). Kuhn's (1970a, 1974, 1977) window on science is history--a fresh kind of historical analysis that



Key:
(1) Thomas Kuhn
(2) Carl Hempel
(3) Sir Karl Popper

Figure 1 The Scientific Theory Profile

x-axis = judgment (theory's value); **y-axis** = representation (theory's truth)



Key:

(1)	Thomas Kuhn	(7)	Stephen Toulmin
(2)	Carl Hempel	(8)	Dudley Shapere
(3)	Sir Karl Popper	(9)	Larry Laudan
(4)	Sociologists of Science	(10)	Imre Lakatos
(5)	Paul Feyerabend	(11)	Clark Glymour
(6)	Gerald Holton	(12)	Ronald Giere

Figure 2 The Scientific Theory Profile

x-axis = judgment (theory's value); **y-axis** = representation (theory's truth) requires one to adopt different world views, to experience a "gestalt-switch," to place oneself inside the natural world of those doing science in a particular discipline at a particular time. His two principal themes are that science must be understood historically, not formally, and all scientific claims to knowledge independent of social context or convention within a discipline must be regarded skeptically. His position on the Scientific Theory Profile is near the y-axis, as his method for judging theories is a practical rationality, involving numerous social and psychological--natural--factors. He is more anti-realist than realist, thus his placement almost halfway below the origin, since he places value on scientific theories only in the particular context in which they are put forth and not as better or closer to a larger goal or truth.

Carl Hempel (Position 2) is the logician in the group. Whereas Kuhn's general account of theories and theorizing requires their being placed within a "paradigm," tradition, or disciplinary matrix through which science works and approaches nature, Hempel's (1965, 1966,1974) is more concerned with the logical structure of theories, their logical confirmation, and the value of auxiliary hypotheses to make them more fruitful. (Hempel departed significantly from the early positivist view that there were clear distinctions between analytic and synthetic sentences in theories, and he abandoned their position that clear distinctions exist between observational and theoretical terms over thirty years ago). He is easy to place in the Rationalist-Realist Quadrant C of the Profile. Proving theories to be true by the way they stand up when tested and by the logical relationship between hypotheses and the evidence given is his primary concern. His standard model of a scientific explanation, called "explication" is well known. His two kinds of explanations, both inferences, are either statistical (probabilistic) or deductive-nomological--where the phenomenon to be explained is to be expected in virtue of certain specific facts or general laws. Hempel (1965) looks for the empirical as well as the logical base in explaining not only physical theories, but functional explanations in biology and in the social sciences--where he claims success in areas normally riddled with teleologcial rather than causal explanations (pp. 251-258).

Sir Karl Popper (Position 3) might be best described as the scientist's philosopher and the philosopher's philosopher. While Hempel deals with the logic of good scientific theories, and Kuhn with the context within which they are conceived and judged, it is Popper (1959, 1965, 1983) who for over fifty years has championed the cause of how science should be done and has nurtured many philosophical disciples. In many ways he has served as the standardbearer for the scientific community at large. His position as a Rational-Realist is different than Hempel's, first because his realism is unique and accepted frequently by scientists today. He views even the best scientific theories, while bringing us closer to the truth, as not completely verifiable. They are only falsifiable--or as Popper prefers, fallible. He agrees with philosophers in the other three quadrants that scientists typically approach what they do with preconceived theories; thus, the observation-theoretical distinction does not exist for him as it did for the positivists with whom he associated earlier in the century. He also stands apart from both Hempel and Kuhn in the belief that since even the best theories are to some degree conjectures, they should proliferate within a given discipline. This goes against Hempel's notion of the confirmability of the best theories and Kuhn's notion of the dominance of one prevailing theory in a mature discipline, when it is in a "normal" and not a revolutionary state.

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Second, Popper's rationalism is different than Hempel's use of logical calculii and standard langauge. It is certainly different than the "natural" rationalism of Kuhn--to be judged only within a particular community of scientists. Instead, Popper has great faith that good scientists, both ancient and modern, carry on a tradition of what he calls "objective rational criticism." This ability to be part of a critical approach towards theories, while doing everyday science, seems to elevate the good scientist above what Kuhn sees possible for normal, puzzle-(not problem-) solving scientists who are bound to working within reigning theories. It is Popper who sees scientists behaving more like philosophers, while Kuhn and, to a lesser extent, Hempel do not.

THE NATURAL ANTI-REALISTS (QUADRANT A)

Whereas three others share the same quadrant with Kuhn, they represent great diversity. The sociologists of science (Position 4) are listed as a group, rather than as individuals, since the emphasis in this study was not on that field. A group of "postmodern" sociologists (i.e. Barnes and Edge,1982) reacted so favorably to Kuhn's writings that they formed a close-knit cadre of supporters who actually took his writings to an extreme, as he has admitted, in terms of what social factors count in theory judgment. Paul Feyerabend (1975; Position 5) has been referred to as the "enfant terrible" in philosophy of science. A brilliant student of Popper, he both rebelled against and embraced his mentor's writings. Insisting that good science has always involved a lot of faith, chaos, play and downright irrationality, he, like Popper, believes in the proliferation of theories. He says, however, that the winning theories could not have arrived at their position without conceit, passion, and prejudice.

Gerald Holton (Position 6) is an interesting combination of physicst/historian-turned-philosopher. Best known to science educators as the father of Harvard Project Physics, the only series in the "alphabet" curricula of the 1960's to have substantial historical and philosophical perspectives, Holton's position is difficult to pinpoint, since his questions are not typically those of a philosopher. Nevertheless, he has important perspectives on the nature of scientific theories. His view about a theory's "truth" is a kind of operational truth, thus he is more anti-realist than realist. Through exhaustive case studies including using the raw data of some of the greats--Einstein, Milliken to name two--he has detemined the importance to scientists of place, time and what he calls the "trajectory" of things at the time. He documents the trajectory of the public shared scientific knowledge in a particular field at the time, the trajectory of the scientist's own activity at the time of a great discovery or event, and any evidence of thematic presuppositions guiding the scientist. Holton's (1978, 1986) work in this realm, particulary on Einstein, is fascinating.

Holton's determination that the developmental nature of scientific theories be presented may have started with his own "trajectory" during his Austrian schooling in the 1930's. He describes the ever-changing map of Europe on one side of the classroom and the Periodic Table of Elements on the other side, presented as a more or less finished product. This of course was brought to the ultimate dichotomy when almost overnight the European map changed to brown, and his instructors showed up the next day in Nazi uniforms (Holton, 1986).

Holton's most compelling evidence that science has maintained an almost charismatic appeal, even through times of great upheaval, is in his insistence that a certain few "themata" travel from generation to generation of scientists forming the parameters within which they work. They are not discipline-bound like Kuhn's reigning theories, but are universal themes--from Einstein to Weinberg, from Copernicus to Russell. He has identified fewer then twenty dyads or triads (in choice) of themata. Einstein believed in symmetry rather than chaos, Weinberg in unification. Newton and Einstein both were synthesizers not analyzers. With reigning themata in place, these scientists sometimes exhibit what Holton calls a "suspension of disbelief." When favorite theories were threatened and things did not turn out experimentally or mathematically as they had hoped, they might ignore aberrant data and obstinately stick to a theory. While not recommending this as good science for novices, Holton sees this persistence often guiding leaders in diverse scientific fields to deeper explanations.

THE RATIONAL-ANTI-REALISTS (QUADRANT B)

The three philosophers placed in this quadrant--Stephen Toulmin, Dudley Shapere, and Larry Laudan--are all writing of newer, broader definitions of rationality. Their anti-realist placement comes from their concentration on the success and quality of scientific knowledge, rather than its truth content.

Stephen Toulmin (1961, 1982; Position 7) is somewhat of a rebel rationalist. He equates objectivity and rationality in the natural sciences with that in all other human sciences. He emphasizes a new "hermeneutic richness," or an interpretive element to all rationality in science. Rather than formal validity there is "rational adequacy." His strong anti-realist position (note point farthest south in quadrant) is sometimes called instrumentalist, where theories are viewed largely as instruments or models for drawing inferences, not as entities to be confirmed or falsified.

Dudley Shapere (1972, 1982, 1984; Position 8) is less of a relativist than Toulmin. He says background beliefs must satisfy strict conditions in order for a scientist to achieve objectivity. It is achievable, however. His dynamic model for science opposes the usual hierarchical one with aims and goals firmly in place, forming the umbrella over methods and theories. He sees them all open to change. His anti-realist position on the Profile comes from his insistence that whatever truth there is to a theory comes down to what works best. His rationalist position is from his insistence that rationality comes about through a body of successful, doubt-free beliefs and whatever body of knowledge is being investigated. The extent that the reasoning can be judged as relevant comes from keeping separate the body of claims from what is under study.

Larry Laudan (1977, 1984; Position 9) is particuairy important to recognize in this quadrant because he was so much a Kuhnian holist in the early 1970's. He has "been there" and now feels compelled to attack Kuhn's "deeply flawed" views of science (Laudan, 1984, p. xiii) and his notion of theory judgment. He attacks most effectively using history of science. History also helps him attack realism and the claims that truth can be known. He says history is full of examples of theories thought to be true based on "epistemic realism" which were later shown not be be--although they were quite successful. He finds untenable the realist claim that there are certain forms of empirical support so likely to give good proofs and evidence that theories exhibiting them can be presumed to be true. His position in Quadrant B comes from his belief in rationalist rules for playing the game of theory judgment, while he holds firm to an anti-realist postition.

Perhaps Laudan's (1984) most enduring contribution is his reticulated (rather than a hierarchical) model of science called the Triadic Network of Justification (p.63). Using history he shows how even great theory

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transitions were much less connected to the prevailing goals and methods than in a hierarchical model. Rather than systematic links he sees varying degrees of mutual dependnce. His model has few constraints on aims or goals. Instead we see theories and aims harmonizing, aims and methods justifying each other, and theories and methods offering some constraints to each other. To Laudan even cognitive values are negotiable, and there is no single right goal for good inquiry. Even mutually incompatible goals can result in successful science. Theories found later to be wrong can be successful, by virtue of their broad explanatory power, their possession of large numbers of confirming instances, their ability to give successful predictions, and their overall fertility. This satisfaction with successful science is good enough for Laudan, but to those in Quadrant C, the Rational Realists, this smacks of relativism, and for them what is successful science is not quite good enough.

QUADRANT C- THE RATIONAL REALISTS

In addition to Popper and Hempel, two other noteworthy philosophers are added to this quadrant. Imre Lakatos (1970; Position 10) stands in the middle of the battle between Popper and Kuhn on such issues as the rationality of faith in one's beliefs (he promotes working within a series of theories and having a whole research program). He disagrees with Popper, whom he describes as considering commitment to one's theories a biological weakness equal to a crime. On the other hand, Kuhn comes under fire for advocating a scientific progress that is like a religious conversion, where mob psychology rules and truth lies in power. Lakatos' message is that a "rational reconstruction" occurs when the "direction of science is primarily determined by creative imagination not the universe of facts which surrounds us" (p. 187). He insists that good, mature theories should allow for novel corroborating, confirming evidence as well as be able to predict novel facts from well-thought-out auxiliary theories and hypotheses. His falsification, unlike Popper's, does not depend on setting down criteria for refutation beforehand and determining which observables count. Instead, his "sophisticated falsification" depends on theories being appraised by how well they hold up when new facts are purposely introduced. The degree to which any theory can be falsified, according to Lakatos is dependent on whether a better theory has emerged.

Whereas Lakatos writes in reaction to Kuhn and Popper, Glymour (1980) (Position 11) writes in reaction to a whole group of contemporary philosophers, including Kuhn and Lakatos, who Glymour contends do not deal at all with how evidence bears on theory. The model to which he responds most favorably is that of Hempel. Glymour seems to add a new dimension to Hempel's version of confirmation, seeming to describe more accurately what actually happens in real science. His argument is that the "holists" as he calls those in the other quadrants are wrong to assume that confirmation cannot occur bit-by-bit. It is in fact this approach that makes Glymour's model perhaps more palatable to those who would find Hempel too unrealistic in his confirmatory precision. This bit-by-bit approach involves the body of a theory together with the evidence producing an instance of hypothesis, and that as further evidence occurs it tests bits of theory by using other bits of theory. He justifies this seemingly circular argument by saying it is the quality of the evidence, to be judged for its relevance and the degree to which it tells against the hypothesis, that really matters.

QUADRANT D THE NATURAL REALISTS

Close reading of virtually all of the scholars mentioned here will alert the reader to two large shifts in contemporary philosophy of science in the last twenty years. One is the value placed on the use of history of science. Some, like Holton and of course Kuhn use it as the basis of their arguments. Others, like Glymour, use history in very specific and restricted ways. In Glymour's case he pays particular attention to the history of scientific argument, thinking of an historical account as a "critical tool for analyzing and criticizing scientific controversies, historical or not" (1980, p.176). Second is the way philosophers of science emphasize today how science is actually practiced rather than how some theoretical science should be practiced. Kuhn was responsible for bringing both history and actual practice to the forefront of critical discussion.

One of the most interesting recent developments in this area--with great possibilities for science educators--can be seen in Quadrant D.

Ronald Giere (1988; Position 12) is essentially alone in this quadrant. It is the most experimental area, and the newest for philosophers to enter. His approach combines and balances well historical considerations, theoretical principles of the new cognitive science, and clinical appraisal with real science. It is for this reason that science educators may find Giere's writings useful. Viewing reigning scientific theories as the best explanations and feeling comfortable with their representing a current truth, Giere is a realist. His theories vary in how well they relate to the real world, and rather than being empirical statements they are families of models or definitions of models. But his explanation for scientists' methods in judging theories comes from the research in cognitive science. These "natural" processes at work within the individual scientist, involving ideas and choices like judgment and representation of theories, is Giere's interest, not the standards of a particular community of scientists so familiar in the emphases of the Quadrant A and B writers (i.e. Kuhn and Toulmin).

Giere labels his explanation as "constructive realism." This is distinct from the purely constructivist views which pay little attention to the biology of human intelligence, and instead emphasize the effect of the environment and sociological explanations, which Giere claims reduce scientific choices to ethnocentric prejudices. Choices that are purely contextual leave one with the impression that yesterday's science was no better than today's--a Kuhnian belief. Giere says this utterly fails to explain the great strides made in science and technology today.

Rather than vague principles of rationality, Giere thinks in terms of the particular strategies individual scientists use and the extent to which they are achieving their goals. He cautiously calls this an "instrumental rationality," noting any use of the term rational as problematic. His scientist is a cognitive agent engaged in a cognitive enterprise.

Giere's methods involve first a detailed analysis of the structure of an advanced physics text, where he looks for evidence of the organization and structure of the discpline's primary theories. He supplements this analysis with clinical observations in a cyclotron lab--recording how physicsts talk, how they build models (noting the ease with which geometric/spatial models are generated, for example), and how they deal with the machinery of physics (trying to determine how they think). From these analyses he has come up with his own model or schema of a theory, maybe even a theory of theories (Giere, 1988, p. 83). His model offers a suggested relationship between sets of statements, models and real systems as well as a partial representation of different families of models.

By rejecting logic and mathematics as the sole justification for good theories, Giere joins most contemporary philosophers of science. But he also substitutes a compelling schema for the empiricist version of theory judgment. In addition, he uses his model for theories to illustrate historical episodes in geology and to offer explanations in molecular biology. For example, he points out that once the schema for DNA was in place, scientists moved rapidly to develop the principal theories explaining modern genetics and synthesis.

This cognitive approach to explaining science by a philosopher offers complementary fodder for science educators working to understand how we construct knowledge. Research on how individuals attain scientific understanding has resulted in provocative, fruitful theories on expert vs. novice systems of representation (Larkin, 1980) and on similarities between theory formation and cognitive maps (Novak, 1981, 1984, 1987). Giere's fresh philosophical approach could aid science teachers in understanding their discpline's current theory organization. Knowing the organization of a discipline's theories would assist teachers in recognizing flaws in students' intuitive thinking, a major responsibility if students are to construct accurate models in science (Linn, 1987).

IMPLICATIONS

If there is any quadrant that represents how most science teachers portray science to their students and how most texts are still written, it is Quadrant C, the Rational Realists. This holdover from the positivist tradition unfortunately does not even do justice to those writing from a Quadrant C position today. Science educators whose knowledge is limited to a few twenty-five year old arguments about how unbiased the scientific observer is or how valid operational defintions are usually fail to notice the balancing which has occurred. The same is true if they have never gone beyond Kuhn's Structure. Philosophers of science emphasizing logic, mathematics, empiricism, and rationality in theory judgment acknowledge the other "natural" factors and deal with them in their writings. Those in opposing quadrants, often deemed relativistic--Kuhn, for example--have moderated much of what was most revolutionary. The dialogue between the writers from all four quadrants--the compromises, the concessions, the admissions of some failures by Popper, Hempel, Kuhn and others--remains hidden to those whose exposure to their writings is non-existent or limited to a course promoting one philosopher's views.

The Scientific Theory Profile can help science teachers develop their own philosophy of science within one of the four quadrants, or they may feel more comfortable taking a position on the origin of the Profile, being knowledgable about different positions and taking a balanced view. In either case, discussions using the Profile with accompanying activities should increase the depth of understanding of science by science teachers.

USING THE PROFILE WITH SCIENCE TEACHERS

The development of goals, objectives and activities for a philosophy of science course for science teachers using the Profile came as a natural extension of this study (see Loving, 1990 for details). Activities were designed using current periodicals, texts, informal science entities, history of science accounts, and popular books in science (comparing Gould and Hawking, for example) to achieve ten enabling objectives. Three example objectives are as follows:

1) evaluate existing philosophical perspectives in texts and curriculum guildes in one's field;

2) analyze one current scientific debate about the quality of rival theories;

3) evaluate the work of a "failed" theorist of the past in science.

Ten terminal performance objectives for the teachers to carry with them to the classroom were set. Three example objectives are as follows:

1) create teaching objectives that are congruent with the dynamic spirit of science;

2) demonstrate the dangers of oversimplifying theories and of ignoring theory change;

3) demonstrate the variety in two different scientific disciplines of methods, degrees of belief, use of intuition, and living with uncertainty

CONCLUSION

The development of the Scientific Theory Profile and the subsequent ideas for a course in philosophy of science for preservice or inservice science teachers is to improve science teachers' understanding of current interpretations regarding scientific theories. Knowing the range of views by well-known thinkers on how theories are judged and represented can lead to clearer perceptions about what science is and what it is not; of the unique and diverse roles that scientific theory has always played in the world of science; and of the dynamic way science is conducted, with elements of art and serendipity as well as tenacity and good science being involved.

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