Conceptual Problems in Theory Appraisal

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Thesis submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

Master of Science

in

Science and Technology Studies

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October, 1988

Blacksburg, Virginia

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(ABSTRACT)

The objective of this thesis is to examine the role of conceptual problems in scientific change, especially in the processes of theory appraisal.

In the thesis I begin with a review of Buchdahl's, Toulmin's, and Laudan's works on conceptual problems. In the review I show that, although all these writers emphasize the importance of conceptual problems as a criterion of theory appraisal, their works on conceptual problems are not complete.

The basis of this thesis is a case study of the nineteenth- century optical revolution. Traditionally, the victory of the wave theory in the revolution was supposed to be due to its empirical successes. However, historical research, presented here, does not support this opinion. I present a different view of the optical revolution, comparing the conceptual problems of wave and particle optics, and identifying the appraisal criteria that historical figures actually employed. I argue that the inferior status of the particle theory in dealing with conceptual problems was the primary cause of the optical revolution.

Based on a generalization of a variety of historical cases of conceptual problems, I offer a new account of conceptual problems. First, conceptual problems are the characteristics of conceptual structures rather than theories. Second, the sources of conceptual problems are the processes of concept application, especially in identifying the existence of a concept's referent, in specifying the properties of its referent, and in explicating the procedure of its application. Third, the primary symptom of conceptual problems is that a conceptual structure becomes meaningless. In conclusion, I present a comprehensive set of categories for classifying conceptual problems.

Acknowledgements

This thesis as well as my graduate study in a foreign country would not have been possible without the help of the faculty members in the Science Studies Program at Virginia Tech.

Foremost, I wish to express my deepest appreciation and gratitude to Dr. Peter Barker, for his keen insights, invaluable advice, and commendable patience to go through draft by draft of this thesis. I am grateful for his profound knowledge to make the thesis writing a significant learning process.

I also wish to convey my gratitude to the other members of the committee: Dr. Roger Ariew, Dr. Albert E. Moyer, and Dr. Robert A. Paterson. They gave much of their time and advice despite their very hectic schedules, and their criticisms and suggestions helped me to avoid a number of mistakes.

I would like to thank Dr. Steve Fuller, for his invaluable comments. I would also like to thank Dr. Larry L. Laudan, whose influences early on my studies help me to conceptualize the subject.

Thank is also given to Li Li, my wife, for her love and support. Finally, to those whose names may have escaped mention here, I offer my sincerest gratitude.

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Chapter I

INTRODUCTION

Although philosophers of science traditionally appraised scientific theories in terms of such empirical factors as degree of confirmation, power of prediction, and degree of falsifiability, Descartes and Kant raised the question of non-empirical criteria for theory appraisal centuries ago. Recent work on non-empirical criteria of theory appraisal, especially the researches of Buchdahl, Toulmin, and Laudan, emphasizes the role that conceptual deficiencies, also called conceptual problems, play in the processes of theory appraisal.

Buchdahl, Toulmin, and Laudan all emphasize the importance of conceptual problems as a criterion of theory appraisal. Their philosophical analyses and historical reconstructions of conceptual problems make convincing cases that conceptual problems as non-empirical appraisal factors are extremely important in the processes of scientific change. However, because their works on conceptual problems are drawn from different theoretical traditions and embedded in different problem situations, they understand conceptual problems differently, and their classifications of conceptual problems are distinct too. Worst of all, due to their incomplete understandings, none of their categories of conceptual problems can cover every historical case presented in their discussions. A further discussion of what conceptual problems are and a more comprehensive set of categories for them are desirable for the research on non-empirical criteria of theory appraisal.

Continuing Buchdahl's, Toulmin's, and Laudan's work on conceptual problems, I plan in this study to conduct a discussion of the basic characteristics of conceptual problems and to develop a more comprehensive set of categories for them. In order to realize this goal, I will use a methodology which is historical and internalist. The underlying assumption of historical methodology, as the term is used in philosophy of science, is that scientific theories are, like human societies and biological species, historical entities. The individuation of scientific theories requires an in-depth historical investigation for their rational appraisal. Under the guidance of this methodology, the research in this paper will be based on actual cases of scientific change, attempting to work backwards from them to an identification of the epistemological assumptions implicit in these cases. An internalist methodological orientation assumes that science is an intellectual enterprise relatively independent of outside influences. Based on this assumption, the research in this paper will focus primarily on the intellectual conditions of scientific change and regard social conditions as secondary.

This study is divided into three chapters. The first chapter is a review of Buchdahl's, Toulmin's, and Laudan's work on conceptual problems. The review will clarify these three writers' opinions on the basic characteristics of conceptual problems and compare their categories for classifying them. The second chapter is a case study of the optical revolution in the beginning of the nineteenth century. The aim of this case study is (1) to expose the inadequacies of the empirical reconstructions of the optical revolution done by Worrall (1976) and Achinstein (1987); (2) to identify a variety of conceptual problems in both the particle theory and the wave theory; (3) to examine the reasons why the scientific community rejected the particle theory and accepted the wave theory in the revolution. The last chapter is a philosophical analysis. Based on a generalization of historical cases, the philosophical discussion will focus on such characteristics as the basis, the sources, and the primary symptom of conceptual problems, and will present a more comprehensive set of categories for conceptual problems.

Chapter II

LITERATURE REVIEW

The research on conceptual problems was mainly done in the 70's by Buchdahl (1970, *et seq.*), Toulmin (1972), and Laudan (1977). The purpose of this chapter is to summarize their works. In reviewing their philosophical discussions and historical reconstructions, I will particularly focus on their classifications of conceptual problems and their understandings of the basic characteristics of such problems.

1. Buchdahl on conceptual problems

In a number of papers published in the 70's (1970, 1972, 1980), Buchdahl develops a series of discussions on the issue of conceptual problems, although he does not use the term "conceptual problems".

The primary motive of Buchdahl's discussions is to look for non-empirical criteria of theory appraisal. In the view of Buchdahl, although falsifiability, confirmation, and predictive power are important criteria for theory appraisal, they are not sufficient. More profound criteria at a "deeper" level, which are certainly not empirical, are required for the choice and acceptability of theories. Following the ideas of Kant, Buchdahl explores the rationale of these criteria of theory appraisal in terms of a neo-transcendentalist approach, which "involves a fresh amalgamation of certain central themes occurring in Kant as well as Husserl, but treated there with insufficient explicitness" (1980, p.1).

Buchdahl divides the criteria of theory appraisal into three distinct categories: constitutive components, explicative components, and architectonic components. Among these three categories, the first one - constitutive components - includes those criteria such as "empirical input, together with logical and mathematical apparatus, and possibly certain inductive justificational principles" (1980, p.4). The other two components - explicative and architectonic - are sharply distinct from the first one, because they are not empirical criteria at all. Buchdahl's discussions of these two criteria constitute his important work on the issue of conceptual problems.

The explicative components of theory appraisal are related directly to the concepts employed in the construction of a scientific theory. The examples of the use of explicative components to evaluate scientific theory include, for instance, Einstein's reflections on the proper meaning of simultaneity, and Descartes's ***a priori*** elucidation of the laws of motion by reference simply to conceptual considerations concerning the notion of motion as a state, the principle of causation, and so on. Such explicative justifications involve first the processes of explicating the meaning of concepts. According to Buchdahl, "the meanings of many terms entering into theories antedate their formulation, still, and especially in a developing science, such meanings are often found to undergo considerable changes" (1970, p.206). As a consequence, the explication of the meaning of concepts is always a precondition for the acceptance of a theory. The explicative components also involve some more profound considerations. Buchdahl indicates that "in some important cases we find that explication of meaning frequently precedes the construction of theories. Also, we should note that quite often such explications, too, have been labeled 'metaphysical,' i.e., 'metaphysical foundations' of the science in question, though once more we shall not worry overmuch about the terminology" (1970, p.207). That is to say, the explication of the metaphysical significance of concepts is another precondition for the acceptance of a theory.

Unlike the explicative components that are concerned with the meaning of concepts, the architectonic components of theory appraisal are concerned with "the art of constructing systems under the guidance of ideas" (1980, p.3). Buchdahl divides those ideas that can guide and determine the construction of an acceptable theory into three basic groups. The first group of such ideas is a series of regulative maxims, such as "maxims of simplicity and economy; considerations of an aesthetic nature; principles of continuity or discontinuity; linkages with general metaphysical notions as for instance 'the real does not change,' 'nothing comes from nothing,' 'the effect is equivalent to the cause'; or more generally, maxims like those of homogeneity, affinity (or the 'analogy of nature'),..." (1970, p.206). The second group of these ideas provides a number of preferred explanation types, for example, "aetiological (mechanistic) vs. teleological; phenomenological (macro; descriptive) vs. gemological (micro; explanatory)" (1980, p.4). The last group of ideas that determines the construction of theories includes desirable patterns of theoretical evolution, for instance, the pattern of consilience of inductions [1](1980, p.4).

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[1] According to Whewell, the consilience of inductions takes place when an induction, obtained from one class of facts, coincides with an induction, obtained from another different class (cf. Butts, 1968, p.138).

In order to illustrate how these three criteria work in the processes of theory appraisal, Buchdahl discusses an historical case - Newton's conception of gravity - in detail. The conception of gravity, in Buchdahl's view, is highly probable according to the constitutive criterion, because it successfully explains and predicts many phenomena of the heavens and of the earth. However, Newton and his contemporaries explicated the conception of gravity in a way that suggests action at a distance. This conceptual explication is obviously inconsistent with a pre-theoretical belief that "matter cannot act on matter at a distance", which is based on an ordinary experience and widely accepted by Newton's contemporaries. Therefore, the conception of gravity is not quite intelligible according to the explicative criterion. Considering this defect, for instance, Locke asserts that gravitational attraction "cannot be conceived to be the natural consequence of that essence [namely, essence of matter; and that it cannot be explained or made] conceivable by the bare essence ... of matter in general, without something added to that essence which we cannot conceive" (cf. Buchdahl, 1970, p.215). In order to overcome this conceptual difficulty, what Newton does is to use the architectonic component to balance the deficiency of the explicative component. Indicating that electric particles have forces by which they act at a distance, Newton insists that the conception of gravity is not improbable because there exist analogous cases (cf. Buchdahl, 1970, p.218 & 1972, p.177).

The introduction of the explicative components and the architectonic components as criteria in theory appraisal certainly brings about a reconsideration of the standards of an acceptable theory, or, the nature of the problems that may make a theory unacceptable. According to Buchdahl, "while the architectonic component determines the 'rationale' of a theory, or of a theoretical concept, explication is concerned with 'intelligibility'" (1970, p.206). That is to say, in addition to truth, intelligibility and rationale should also be regarded as the criteria of an acceptable theory, and, based on the same considerations, lack of intelligibility or rationale are the major problems that make a theory unacceptable. However, what exactly do the notions "intelligibility" and "rationale" mean here? And what are the nature of those problems that arise from lack of intelligibility or rationale? Buchdahl does not answer these questions directly. Fortunately, it is not difficult to find his view implied in his discussions.

In Buchdahl's discussions, those problems that arise from lack of intelligibility or rationale at first occur in the processes of concepts' employments or applications. In the discussion of the explicative components, Buchdahl realizes that the processes of explications are not related to a single, isolated concept, but to "the concepts employed in the construction of a scientific theory" (1970, p.206). Also, he indicates that only "in the light of considerations connected with the theoretical and experimental field forming part of the theory in question" can the origin or the new meaning of a concept be understood (Ibid.). That is to say, the problems about the explication of a concept's meaning are the difficulties existing in the cases in which concepts are applied to new theoretical constructions or experimental fields. A similar understanding can also be found in Buchdahl's discussions of architectonic components, in which he regards the failure in consilience of inductions as one of the symptoms of the problems that stem from the lack of intelligibility or rationale. Generally speaking, consilience of inductions can be understood as a coherence between different concepts' applications so that the success of one concept's application can support the other's applications. Thus, part of the problems of theory construction arises also from the difficulties existing in the application procedures of the theory's concepts.

In addition to the difficulties existing in the applications of concepts, Buchdahl also suggests that the problems that stem from lack of intelligibility or rationale have a deeper meaning. In the discussions of the explicative components, he indicates the existence of pre-theoretical explications that are concerned with the metaphysical significance of concepts. In the discussions of the architectonic components, he points out that the regulative maxims and explanation types "originate as expressions of the metaphysical basis of science" (1980, p.3). That is to say, the problems stemming from lack of intelligibility or rationale also exhibit themselves as the difficulties about the metaphysical significance of concepts or about the metaphysical foundation of theories.

In short, the problems related to the meaning of concepts and the construction of theories, which are in fact conceptual problems, are mainly understood by Buchdahl as the difficulties about the application and the metaphysical foundation of concepts used in those theories.

2. Toulmin on conceptual problems

Toulmin develops ideas on conceptual problems in his theory of the evolution of concepts. In a section of his *Human Understanding* (1972), entitled "The Nature of Conceptual Problems in Science", Toulmin discusses the issue of conceptual problems.

In the view of Toulmin, scientific problems result from the gap between an explanatory ideal and the current explanatory capabilities of sciences[2]. And conceptual problems, specifically, result from the gap between an explanatory ideal and the explanatory procedure of the theory. Normally, Toulmin believes, the various explanatory procedures of a science give us effective command over only certain parts of its current domain. In a few cases, the explanatory procedures associated with different coexisting

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[2] Unlike logical empiricists who define explanation as a deductive argument, Toulmin understands explanation mainly as an intellectual activity, which may or may not include formal argument as its end product (cf. Toulmin, 1972, p.157).

theories may even be formally inconsistent. "More typically, there will be a direct competition between coexisting concepts and procedures. This gives rise to pressures along the boundaries between the ranges of application of different concepts, each of which aims to extend its range to include phenomena previously dealt with using some other procedure" (1972, p.177). This kind of pressure, existing at the boundaries of a theory's domain, brings about conceptual problems.

Toulmin classifies five different kinds of conceptual problems, based on the way in which they arise.

The first class of conceptual problems that Toulmin identifies occurs when the current explanatory procedures of concepts are extended to fresh phenomena. "[T]here are always certain phenomena which a natural science can reasonably be expected to explain, yet for which no available procedure yet provides a successful treatment" (Ibid.). For instance, the 19th-century physicists reasonably expected double refraction to be explained by geometrical optics but no explanation was forthcoming. The pressure of extending the explanatory procedure of geometrical optics to cover double refraction therefore became a conceptual problem for the theory.

Another class of conceptual problems similar to the first class arises when the current explanatory procedures are extended to gain more precise explanations. "[T]here are always some phenomena which can be accounted for up to a point using current explanatory procedures, but for which scientists would welcome more complete or more precise explanations" (Ibid.). For example, the kinetic theory was required to extend its procedure to account for the more precise measurement of the phenomena of gases. This extension resulted in a conceptual problem and the solution of it was the van der Waals equation.

Unlike the first two classes of conceptual problems that spring directly from the considerations of unexplained phenomena, the next two classes of conceptual problems arise at the intellectual boundaries where current concepts and procedures approach, overlap, or conflict. Specifically, the third class comprises the problems that arise when we consider the mutual relevance of different coexisting concepts within a single branch of science, for example, when the procedures of quantum mechanics are used to 'take over' the scopes of particle and wave optics (1972, p.179). The fourth class comprises those problems concerned with the mutual relevance of concepts from different branches of science, for instance, when the procedures of physics are used to cover the domain of chemistry (Ibid.).

The final class of conceptual problems Toulmin identifies "arise out of conflicts between concepts and procedures current within the special sciences and ideas and attitudes current among people at large" (1972, p.180). The conflict between the 17th-century mechanical theory which reduced the cosmos to a self-operating machine and certain theologies which sought to preserve the role of God belongs to this kind of conceptual problems.

Another important aspect of Toulmin's work is the discussion of the characteristics of conceptual problems. In this discussion, he insists on the differences among empirical problems, formal problems and conceptual problems.

Toulmin asks philosophers, "in tackling conceptual problems, is it our business to find out simply what is in fact the case about the world? Or are we, alternatively, simply reordering and improving the mathematical-linguistic formalisms used in talking about the empirical phenomena concerned?" In the view of Toulmin, conceptual problems are neither questions about the world nor attempts to improve a theory's formalism. He asserts that "it would be equally misleading to describe conceptual issues in either of those ways alone" (1972, p.186).

According to Toulmin, empirical problems merely invite us to extend the application of existing concepts to new cases and never call in question the status of the concepts. The general form of empirical problems may be as follows: Granted that we know how to apply a well-established concept C to the instance x, we are asking, what then is true or false of x in respect of the concept C? On the other hand, formal problems merely invite us to reorganize our symbolisms internally and never challenge the merits of the relevant concepts and procedures. The general form of formal problems may be as follows: Granted that we know how to work with a well-established concept C, we are asking, how can we best present the implications of applying the concept C to anything whatever? (1972, p.187)

In contrast to empirical and formal problems, Toulmin claims that solving conceptual problems enables us to construct better explanatory procedures. Therefore, the general form of conceptual problems is: Granted that we do not in all cases know how to apply the concept C in its present form, we ask, "can any alternative procedures be developed, for applying those concepts - with suitable modifications - to recalcitrant cases also?" (1972, p.188). In other words, conceptual problems primarily raise concerns about the explanatory adequacy and explanatory merits of our current explanatory procedures. Thus, the nature of conceptual problems is in fact understood by Toulmin in terms of difficulties about the explanatory procedures of current concepts, or more generally, the applications of current concepts.

3. Laudan on conceptual problems

Laudan's earliest discussion of conceptual problems can be found in his comment on Buchdahl's paper in 1970. In this comment Laudan argues that, unlike what Buchdahl describes, the charge that Newton's gravity was occult is neither explicative nor architectonic consideration, but "a fourth important criterion of choice" which he calls the "metaphysical" or "reductive" component (1970, p.233). Laudan claims that

> The reductive component generally specifies a set of entities, qualities, and modes of interaction which are regarded as both real and basic. These privileged entities are viewed as 'unexplained explainers' (to use Sellars's language) and a scientific theory or hypothesis is adequate (at the reductive level) if and only if it can be expressed or explained in terms of the privileged ontological categories" (1970, pp.233-234).

Laudan's mature and comprehensive view of conceptual problems is presented in his 1977 book, *Progress and Its Problems.*

Laudan's motive for introducing the notion of "conceptual problems" in his theory of scientific growth lies in his concern to maintain the rationalist tradition in philosophy of science (1977, pp.3-5). In the history of science, there were many scientific controversies where the empirical support for rival theories was essentially the same. For instance, the debates between Copernican and Ptolemic astronomers, between Newtonians and Cartesians, and between wave and particle optics. In these cases, theory appraisals had to be based on nonempirical considerations. Traditionally, philosophers of science have generally taken the existence of nonempirical considerations as a token of the irrationality of science. Being dissatisfied with such irrational interpretations of scientific controversies, Laudan introduces "conceptual problem" to describe those nonempirical considerations in the process of theory appraisal. By regarding the ability to solve conceptual problems as an important and rational dimension of theory appraisal, Laudan hopes that he can both reconstruct those historical cases of scientific controversies precisely and interpret them rationally (1977, pp.45-8).

One of the major concerns of Laudan's work is to formulate a typology of conceptual problems. He divides conceptual problems into two very different kinds, internal and external conceptual problems, according to the sources from which they arise.

Internal conceptual problems, Laudan says, occur when a theory "exhibits certain internal inconsistencies, or when its basic categories of analysis are vague and unclear" (1977, p.47). One of the typical examples of such internal conceptual problems, Laudan believes, can be found in Newton's physics. The major criticisms of Newton's contemporaries (including Locke, Berkeley, Huygens, and Leibniz) concerned the conceptual ambiguities and confusions in Newton's foundational assumptions. What was absolute space and why was it needed in physics? How could bodies conceivably act on one another at-a-distance? What was the source of the new energy which had to be continuously super-added to the world order? All of these questions raised acute difficulties for Newton's theory even though it could solve many empirical problems.

External conceptual problems, on the other hand, are defined by Laudan as the troubles arising when a theory is in conflict with another theory or doctrine, which is regarded as rationally well founded (1977, p.49). Laudan goes on to ask what sorts of theories can be paired with a scientific theory to generate an external conceptual problem. He identifies the following three kinds of theories as the sources of external conceptual problems. First, other scientific theories may generate some kind of intra-scientific difficulties (1977, p.55). For instance, the inconsistencies between the accepted Aristotelian physics and Copernicus's heliocentric astronomy brought about serious difficulties for Copernicus's theory, according to Laudan. Secondly, methodological principles may result in normative difficulties. For instance, eighteenth-century methodology regarded only hypotheses inductively inferred by simple generalization from observation as legitimate. This methodology caused troubles for Newtonian theory, which postulated the existence of imperceptible particles (1977, pp.57-61). Finally, metaphysical, ethical, theological, and even non-scientific ideas may cause worldview difficulties (1977, pp.61-63).

Another important aspect of Laudan's work is his understanding of the characteristics of conceptual problems. Laudan's clearest statement of the definition of conceptual problems is as follows:

> If empirical problems are first order questions about the substantive entities in some domain, conceptual problems are higher order questions about the well- foundedness of the conceptual structure (e.g. theories) which have been devised to answer the first order questions (1977, p.48).

In this definition, the word "well-foundedness" is the key to figuring out Laudan's understanding of the characteristics of conceptual problems. But what is the exact meaning of "well-foundedness"? Laudan does not give any direct answer to this question. Fortunately, in Laudan's concrete examples, especially in those about the kinds of connections between theories when he analyzes external conceptual problems, we can find Laudan's answer, by implication.

In Laudan's account, external conceptual problems are generated from the conflict or tension between theories. He emphasizes that "it is the existence of this 'tension' which constitutes a conceptual problem" (1977, p.51). But what precisely do the "tension" and the "conflict" amount to?

Laudan understands the cognitive relationships between two or more theories primarily as a logical relationship. He outlines five various relationships which may exist between theories: (1) Entailment - one theory entails another theory. (2) Reinforcement - one theory provides a "rationale" for (a part of) another theory. (3) Compatibility - one theory entails nothing about another theory. (4) Implausibility - one theory entails that (a part of) another theory is unlikely. (5) Inconsistency - one theory entails the negation of (a part of) another theory. Based on this taxonomy of the various cognitive relationships between theories, Laudan claims that "in principle, any relation short of full entailment (1) could be regarded as posing a conceptual problem for the theories exhibiting it" (1977, p.54). Therefore, not only logical inconsistency between theories constitutes a conceptual problem, but any inter-theory relationship which is short of full logical entailment, such as joint implausibility, mere compatibility but not reinforcement, and mere reinforcement but not entailment, should be regarded as conceptual problems.

In short, external conceptual problems are regarded by Laudan as the defects of the logical relationships between two or more theories.

A similar understanding can also be found in Laudan's analysis of internal conceptual problems. Although he admits the existence of other kinds of internal conceptual problems, Laudan says that "the most vivid, though by no means the most frequent, type of internal conceptual problem arises with the discovery that a theory is logically inconsistent, and thus self-contradictory" (1977, p.49). In Laudan's eyes, therefore, at least part of internal conceptual problems consists in the defects of the logical relationships within a theory.

Based on Laudan's analyses of internal and external conceptual problems, it is clear that the word "well-foundedness" in Laudan's work refers to the status of the logical relationships within a theory and between two or more theories, with entailment taken as the perfect state. The violation of such a state of well-foundedness constitutes the sources of conceptual problems. Compared to his early view (1970), Laudan's understanding of conceptual problems has changed considerably by 1977. In his mature version, conceptual problems are no longer understood as troubles about the metaphysical foundations of a theory, but as difficulties of the logical well-foundedness of a theory.

Although Buchdahl's, Toulmin's, and Laudan's work on conceptual problems are drawn from different theoretical traditions and embedded in different problem situations, all these writers emphasize the importance of conceptual problems as a criterion of theory appraisal. Their philosophical analyses and historical reconstructions of conceptual problems make convincing cases that such non-empirical appraisal factors as conceptual problems are extremely important in the processes of theory appraisal.

Buchdahl's, Toulmin's, and Laudan's works also provide us with descriptions of various kinds of conceptual problems. Although the classifications of conceptual problems these authors give are different, there are still areas of overlap. For example, Laudan's external conceptual problems, such as inconsistency and mere compatibility but not reinforcement, are similar to those described by Toulmin which arise at the intellectual boundaries. Other kinds of Laudan's external conceptual problems, those corresponding to joint implausibility and mere reinforcement but not entailment, can easily be put into Buchdahl's categories, because whether a theory makes another theory unlikely (implausibility) or whether it provides a rationale for another theory (mere reinforcement) is the business of architectonic justification. Finally, the first two kinds of conceptual problems described by Toulmin can also be understood as difficulties that arise when concepts are applied to an experimental field and thereby coincide with part of Buchdahl's explicative components. Therefore, it is probable that we will be able to develop a coherent classification of conceptual problems based on Buchdahl's, Toulmin's, and Laudan's description.

There is no doubt that Buchdahl's, Toulmin's, and Laudan's view on conceptual problems are not completely consistent. One of the essential differences among them is about the basic characteristics of conceptual problems. While Buchdahl and Toulmin regard the subject matter of conceptual problems mainly as single concepts used in a theory and interpret conceptual problems as the difficulties of a concept's application and a concept's metaphysical significance, Laudan defines conceptual problems mainly through corresponding theories and reduces conceptual problems primarily to some kind of logical difficulties. The existence of these distinct or even inconsistent understandings requires a further exploration of the basic characteristics of conceptual problems, which constitutes the major concern of the following chapters.

Chapter III

HISTORICAL CASE STUDIES

Buchdahl's, Toulmin's, and Laudan's work on conceptual problems indicate a new dimension needed to understand the issue of theory appraisal or theory choice. The major purpose of this chapter is to examine Buchdahl's, Toulmin's, and Laudan's view on conceptual problems in a concrete historical case of theory appraisal - the optical revolution, that is, the replacement of particle optics by wave optics at the beginning of the nineteenth century.

Traditionally, the optical revolution was reconstructed by philosophers of science along an empirical dimension. For a long period, for instance, the cause of the optical revolution was attributed to "crucial experiments" such as Foucault's experiment on the velocity of light (Sabra, 1954, pp.149-51). Although Lakatos severely criticized this account, calling the opinion that accounted for the optical revolution solely by "crucial experiments" naive "instant rationality" (Lakatos, 1978, p.68 & 72n), Lakatosians continued to interpret the optical revolution as a result of the empirical degeneration of the particle theory and the empirical progress of the wave theory (Worrall, 1976). Recently, Achinstein (1987) also claimed that the optical revolution resulted from the fact that the particle theory had low probability while the wave theory had high probability, assigning probabilities only based on empirical factors. Do these exclusively empirical reconstructions of the optical revolution expose the nature of the historical case precisely? In addition to empirical factors, are there any non-empirical factors that play a role in the theory appraisal in the optical revolution? And can Buchdahl's, Toulmin's, and Laudan's work on conceptual problems become a tool in the reconstruction of the optical revolution? These are the major questions I try to answer in this chapter.

In the following sections, I will first introduce two empirical reconstructions of the optical revolution (by Worrall and Achinstein) and expose their difficulties; then I will try to improve the reconstruction of the optical revolution based on Buchdahl's, Toulmin's, and Laudan's view on conceptual problems and argue that the comparison of conceptual problems between rival theories is an important criterion of theory appraisal in the optical revolution.

1. Worrall's reconstruction of the optical revolution

In Lakatos' theoretical model of scientific change the basic unit is a research program that consists of a sequence of theories. This sequence of theories is unified by a hard core of metaphysical assumptions and an heuristic principle which specifies the direction of new research. Although the heuristic may vary to some extent, the core is unchangeable through the whole period as the program evolves. Based on this model, Lakatos reduces scientific revolutions to the replacement of a degenerating research program by a progressive program. Such replacement only occurs when one of the competing programs can make novel predictions not made by its rival (theoretical progress); has more predictions corroborated by experiments than its rival does (empirical progress); and produces these results under the guidance of its heuristic principle while its rival can only accommodate these results in an ***ad hoc*** manner (heuristic progress) (Lakatos, 1978, p.33, 34, 179).

Worrall (1976) gives a reconstruction of the optical revolution based on Lakatos's model. He tries to show why the wave program replaced the corpuscular program in the late 1820's to early 1830's rather than in early 1800's when the major principles of the wave program had already been established by Young.

One of the most important tasks in any Lakatosian reconstruction is to identify the competing hard cores and heuristic principles. In Worrall's case, he provides a clear identification of the cores and the heuristics of both optical programs. For the corpuscular program, Worrall indicates, the belief that light consists of corpuscles emitted from luminous objects constituted its hard core, and the reduction of all optical phenomena to particle mechanics constituted its heuristic. Similarly, the core of the wave program was the belief that light is a disturbance in an all-pervading elastic medium, and its heuristic was the reduction of all optical phenomena to the mechanics of elastic media, without invoking any force not already made available by theoretical mechanics (Worrall, 1976, P.156 & 136).

Worrall also tries to analyze the causes of the optical revolution by using the notions of empirical and heuristic progress provided by Lakatos. According to Worrall, neither the corpuscular nor the wave program could make empirical progress in the first two decades of the nineteenth century: Both programs were in the business of ***post hoc*** explanation. However, because of the comparatively less developed state of the mechanics of elastic media relative to the mechanics of rigid particles, the heuristic of the corpuscular program was rather more definite than that of the wave program and hence superior to it. This situation did not change until Fresnel's analyses of diffraction and polarization which provided a great many successful predictions about various optical phenomena. Therefore, the conditions for the occurrence of the optical revolution were not satisfied until Fresnel's work, which made the wave program empirically progressive in comparison to the corpuscular program (Worrall, 1976, p.161).

By indicating the empirical difficulties and the heuristic inferiority of Young's work, Worrall convincingly reveals the reasons why the optical revolution could not be brought about by Young. But Worrall's attempt to attribute the revolution mainly to Fresnel's empirical successes meets several difficulties.

The first difficulty results from Worrall's overestimation of the empirical progress made by Fresnel. Although the wave program indeed made a great deal of empirical progress after Fresnel's work, its competition with the corpuscular program in this respect was inconclusive. This situation stemmed from the following three defects of the wave program in explaining optical phenomena: First, Fresnel's theory failed to provide explanations for known optical phenomenon even in early 1830's. In particular, Fresnel admitted that his theory was not able to explain refractive dispersion and selective absorption (Fresnel, 1829, p.161); In addition, he even made no attempt to explain some phenomena associated with polarization, for example, why circular polarization only exists in the rays which pass near the axis of a crystal. According to Brewster, Fresnel seemed to have shrunk from this difficulty (Brewster, 1832, pp.315-6). Secondly, even the Young-Fresnel transverse wave theory still used ***ad hoc*** explanations of some optical phenomena. In order to account for the phenomenon of "inequal refrangibility", for instance, Young had to suppose that the material particles of transparent bodies were susceptible of permanent vibrations, somehow slower than the undulations which produced them (Brewster, 1832, p.317). Thirdly, some of the predictions provided by Fresnel's theory were disconfirmed by experiments. Although a direct measurement of the speed of light through different media was not achieved in the early 1830's, Potter conducted an indirect measurement of the relative velocities of light in air and in glass. He reported that his experiment disconfirmed Fresnel's prediction that the light slowed down upon entering a more dense medium (Potter, 1833, pp.81-94). Potter's experiment became a serious difficulty for the wave theory. Even Hamilton, who accepted the wave theory, admitted that if Potter's experiments were correct "they would furnish a formidable and, perhaps, fatal objection against the undulatory theory of light" (Hamilton, 1833, p.191).

The second difficulty of Worrall's reconstruction results from his overestimation of the positive effect of empirical progress. Worrall believes that the empirical progress made by Fresnel was so powerful that it could force people to reject the corpuscular program and accept the wave program. As a matter of fact, however, the empirical progress made by the wave program did not make the corpuscular theorists give up their theory and directly bring about the revolution. The corpuscular theorists never thought that the empirical successes of the wave program would raise any serious difficulty for them. In 1824, for example, Biot expressed hope that the corpuscular program would one day be able to make empirical progress in the areas where it presently failed (Frankel, 1976, p.162); and in 1833, Brewster still denied the value of the wave program's empirical success by claiming that to explain and predict facts was by no means a test of a theory's truth (Brewster,1833, p.361).

Since Fresnel's wave theory still had several defects in explaining optical phenomena and corpuscular theorists were not impressed by the empirical progress the wave program was making, it is hard to accept Worrall's account of the optical revolution in terms of Lakatosian empirical progress alone. On the other hand, Fresnel's theory did not change the heuristic status of the two programs. The heuristic of the wave program was still inferior to that of the corpuscular program, at least according to Worrall's standard. Thus, Worrall's reconstruction based on Lakatos' model fails to explain why the optical revolution could occur in the late 1820's to early 1830's.

2. *Achinstein's reconstruction of the optical revolution*

Achinstein (1987) supplies another reconstruction of the optical revolution mainly based on Bayes's theorem.

The major question Achinstein asks in his 1987 paper is what method nineteenth-century wave theorists employed in practice. Unlike Laudan and Cantor who hold that nineteenth-century defenders of the wave theory used a form of the method of hypothesis, Achinstein argues that "19th-century wave theorists such as Young, Fresnel, Lloyd and Herschel, typically employed a method that is significantly different from the method of hypothesis" (1987, p.295). In publications setting forth arguments for their theory, Achinstein says, wave theorists actually employed a type of eliminative method that consists of the following four parts:

(1) Start with the assumption that light is either a wave phenomenon or a stream of particles. This assumption is in part an inductive one based on the fact that light travels with a finite velocity and that the most common kinds of things that have been observed to do this are waves and particles (1987, p.298, 312).

(2) Show how each theory explains various observed optical phenomena, for example, rectilinear propagation, reflection, refraction, diffraction, dispersion, etc. (1987, p.299).

(3) Show that the particle theory in explaining one or more of the observed optical phenomena introduces improbable hypotheses, while the wave theory does not. For

example, Young indicates that the particle explanation of diffraction at an aperture includes an improbable hypothesis supposing that bodies of different forms and of various refractive powers should possess an equal force of inflection; and Lloyd asserts that the particle explanation of the velocity of light involves an improbable hypothesis that assumes the existence of a special interaction between light particles and our organ of vision (1987, pp.299-301).

(4) Conclude that the wave theory is (very probably) true, while the particle theory is (very probably) false (1987, p.301). According to Achinstein, this conclusion is reasonable because, based on Bayes's theorem, it can be proved that the low probability of the auxiliary hypothesis of the particle theory necessarily leads to the low probability of the particle theory itself; and in the circumstance that there only exist two rival theories, the low probability of the particle theory implies a high probability of the wave theory (1987, pp.308-312).

By describing the characteristics of the method that nineteenth-century wave theorists employed, Achinstein actually provides a reconstruction of the optical revolution in which the degree of the probability of a theory is the primary criterion that wave theorists used in theory appraisal. In other words, the cause of the revolution is interpreted in Achinstein's reconstruction primarily as the low probability of the particle theory and the high probability of the wave theory.

Undoubtedly, it is appropriate to reconstruct the optical revolution through searching the methods and criteria that the historical figures actually employed in their theory appraisal. But Achinstein's attempt to attribute the cause of the revolution mainly to the low probability of the particle theory has several difficulties.

The major difficulty consists in the fact that Achinstein's reconstruction does not coincide with the historical facts, even those he chooses, so that it fails to reveal the real historical cause of the revolution.

In Achinstein's reconstruction, showing that the particle theory introduces improbable hypotheses in its explanations is the key step in the theory appraisal that wave theorists made. But what makes the auxiliary hypotheses of the particle theory improbable? According to Achinstein, the improbability arises from the fact that these auxiliary hypotheses do not get empirical support from the observations and background information, or, using his own words, the "inductive weight" of these auxiliary hypothesis is very low (1987, pp.310-312). However, if we examine the historical examples Achinstein introduces, it is very difficult to agree with Achinstein's opinion.

The first example Achinstein introduces to illustrate that wave theorists actually used probability as a criterion in theory appraisal is Young's criticism against the particle explanation of diffraction at an aperture. In order to explain the phenomenon of diffraction, particle theorists introduced an auxiliary hypothesis that diffraction is caused by an attractive force exerted at the edges of the aperture. In the view of Young, this auxiliary hypothesis is unacceptable, because "there is some improbability in supposing that bodies of different forms and of various refractive powers should possess an equal force of inflection, as they appear to do in the production of these effects" (Young, 1807, p.457). Thus, according to Young, the auxiliary hypothesis is improbable because it requires supposing that bodies of different forms and different refractive power should have equal power of inflection, or, more generally, because it violates a metaphysical axiom that different causes should have different effects. This kind of conflict with a metaphysical principle, clearly, can be easily put into Buchdahl's category of architectonic component; or, Laudan's category of external conceptual problems; or, Toulmin's last type of conceptual problem. This example therefore shows that the "improbability" of the auxiliary hypothesis, even in the eyes of Young, actually stems from the conceptual defects of the hypothesis rather than from lack of inductive weight.

Another example Achinstein introduces is Lloyd's criticism against the particle explanation of the observed constant velocity of light. The difficulty in this explanation is that if light consists of particles then the velocity of light would not be a constant but would depend on the mass of the body emitting the light, because the mass of the body would exert an attractive effect on the particles of light and thereby create a corresponding retardation of their velocities. In order to explain the observed constant velocity of light, Arago introduces the auxiliary hypothesis that particles of light are emitted with different velocities, but that our eyes are sensitive to light of just one particular velocity. In the view of Lloyd, Arago's auxiliary hypothesis is improbable even though it has some support from the discoveries of Herschel, Wollaston, and Ritter, respecting the invisible rays of the spectrum. It is improbable because it is not "easily reconciled with hypotheses which we are able to frame respecting the nature of vision" (Lloyd, 1834, p.301). It is also clear that the improbability of Arago's hypothesis is attributed by Lloyd not to lack of empirical support but to conflict with the accepted knowledge of vision.

In short, the historical cases suggest that the theory appraisal conducted by wave theorists in the optical revolution involves not only empirical components but non-empirical, specifically, conceptual components. A variety of conceptual problems which result in the difficulties of the particle theory are found and used by wave theorists against the particle theory. Without mentioning these conceptual problems, Achinstein's reconstruction fails to expose the cause of the revolution properly.

3. A new reconstruction of the optical revolution

The failures of Worrall and Achinstein's reconstructions indicate that the traditional empirical approach does not make full sense in the case of the optical revolution, because in this case it is hard to make a complete appraisal if we limit our attention to such empirical components as the explanatory power and the predictive power of both optical theories on the eve of the revolution.

In fact, on the eve of the optical revolution (the first two decades of the nineteenth century), there was no obvious difference in the power of explanation or prediction between the corpuscular and the wave theory. On the one hand, the corpuscular theory, including the works of Laplace, Biot, and Brewster, continued to expand its domain of solved empirical problems in this period. Its progress primarily resulted from a new methodological principle introduced by Laplace. In order to explain various optical phenomena that were not accounted for simply by Newton's inverse-square law, Laplace put forward a new methodological principle reducing every optical phenomenon to the effects of molecular forces that only exist at short-range and are either attractive or repulsive. Under the guidance of this new methodological principle, the corpuscular theory did solve many empirical problems associated with double reflection and polarization, which belonged to one of the research frontiers of optics at that time (Fox, 1974, p.95 and Frankel, 1976, p.152). On the other hand, the wave theory, primarily consisting of Young and Fresnel's theories, also continued to enlarge the domain it could cover. It did successfully explain the phenomena associated with diffraction, which was another research frontier of optics at that time, first using Young's principle of interference, then using Fresnel's model of a transverse wave, which contained a different ontological assumption from the longitudinal wave model used by the predecessor wave theories.

It is quite clear that both the corpuscular theory and the wave theory had made empirical progress on the eve of the optical revolution. It is very hard to compare them by measuring the number of empirical problems they could solve. Also, it is difficult to compare them by considering the 'adhocness' [3] in the explanations of both traditions, because scientists at that time had no way of knowing whether an explanation which sounded ***ad hoc*** would at some later point be able to produce novel predictions. Therefore, 'adhocness' was not a practically feasible standard for appraising rival research traditions. Since comparing empirical problems cannot provide convincing reasons to account for the occurrence of the optical revolution, we should focus our attention on the conceptual problems of both rival theories.

Although the corpuscular theory could explain a rather large range of optical phenomena, its ability to solve empirical problems was maintained at the price of creating some serious conceptual problems.

One kind of conceptual problems the corpuscular theory had arises from the explanations of the phenomenon of diffraction. In addition to the one already pointed out by Young (see p.25), for example, a further problem arose when Brewster tried to explain the phenomena of diffraction. He assumed that the force between optical particles did not depend on the mass of one of them (Cantor, 1983, p.187). This hypothesis is obviously incompatible with the inverse square law of mechanics and thereby creates a conceptual problem, which can be understood as an incompatibility between theories and put into Laudan's categories of external conceptual problems, or can be understood as a conflict between concepts that arises at the intellectual boundaries within a single

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3 When a theory is modified to accommodate an experimental failure, the modification is ***ad hoc*** if it has no testable consequence beyond the explanation of the original failure.

branch of science and put into the third kind of conceptual problems in Toulmin's categories .

More conceptual problems for the corpuscular theory occur in the explanations of the phenomenon of double reflection. When Laplace deduced the Huygenian law of double refraction within the framework of the corpuscular tradition, he had to introduce a "necessary condition" in the effect that the velocity of the extraordinary ray depended solely on the direction of its motion with respect to the axis of the crystal (cf. Young, 1809, p.224). This "necessary condition" became a target of Young's criticism. When Young reviewed Laplace's explanation, he pointed out that, according to Newtonian mechanics, for every body under a central force, its velocity could only be a function of its position in space. Laplace's "necessary condition", which assigned velocity by the direction of motion, was therefore incompatible with the Newtonian concept of central forces (Young, 1809, p.225). This incompatibility also brings about a conceptual problem which perfectly fits into Laudan and Toulmin's categories.

Another conceptual problem in Laplace's explanation of the law of double refraction comes from his notion of ellipsoidal construction. This notion was introduced solely for the purpose of deduction: It did not correspond to any physical entity and did not have any physical meaning (cf. Young, 1809, p.225). When Young reviewed Laplace's paper, he pointed out that it was not satisfactory for Laplace to attribute physical meaning to the notion of ellipsoidal construction in astronomy but to leave the same notion physically meaningless in optics (cf. Young, 1809, p.228). The physically meaningless notion creates a problem about its metaphysical significance, and therefore, a conceptual problem belonging to the aspect Buchdahl calls explicative components.

A similar conceptual problem can also be found in Brewster's explanation of double refraction. In this explanation, Brewster had to introduce a special kind of force produced by the crystalline axes to determine whether a particle of light was refracted in an ordinary or extraordinary way (Steffens, 1977, pp.142-7). Although the concept of crystalline forces was crucial for the his explanation, Brewster did not express it clearly. In particular he did not specify why the forces could vary for each axis and how they could have either a repulsive or an attractive effect depending on the arrangement of the axes. This vague, unclear notion of crystalline forces brings about an internal conceptual problem in the sense of Laudan's classification. The conceptual problem of this notion can also be classified as a failure in explicating the meaning of the notion, and therefore belongs to Buchdahl's explicative components.

All of these conceptual problems, including the external inconsistencies and internal vagueness, became the major targets of wave theorists' attacks. When Lloyd compared the wave tradition and the corpuscular tradition in his 1834 report on the progress of physical optics, he wrote:

> An unfruitful theory may, however, be fertilized by the addition of new hypotheses. By such subsidiary principles it may be brought up to the level of experimental science, and appear to meet the accumulating weight of evidence furnished by new phenomena. But a theory thus overloaded does not merit the name. It is a union of unconnected principles, which can at best be considered but as supplying the materials for a higher generalization. Its very complexity furnishes a presumption against its truth; for the higher we are permitted to ascend in the scale of physical induction, the more we perceive of that harmony, and unity, and order, which must reign in the works of One Supreme Author. The theory of emission, in its present state, exhibits all these symptoms of unsoundness (Lloyd, 1834, p.296).

Based on this principle, Lloyd objected to the corpuscular theory simply because it explained optical phenomena only by means of an agglomeration of unconnected and inconsistent notions and therefore failed to give us a harmonious and united picture. Also, when Whewell summarized the cause of the corpuscular tradition's failure, he also claimed that it was these "incoherent" notions that finally "overwhelm[ed] and upset the [corpuscular tradition's] original framework" (Whewell, 1857, Part II, p.340).

In contrast to the corpuscular theory, the wave theory did not have such serious conceptual problems on the eve of the optical revolution. The wave theory had the advantage of being amenable to mathematical expression, and therefore was easily expressed in a highly consistent form. Moreover, through the work of Fresnel, the original conceptual problems existing in the wave theory in the first two decades of the nineteenth century were considerably reduced by the eve of the revolution. When Young explained the phenomena of diffraction and interference, for example, his concept of light was rather vague: When light propagated he treated it as consisting of rectilinear rays, but when the rays of light crossed he attributed wave character to them (Young, 1804, p.180). Since waves spread in all directions, the wave character of light is not consistent with its character of rectilinear propagation. This conceptual problem of the wave theory was not solved until the end of the second decade. By combining Huygens's principles with the principle of interference, Fresnel (1866-70; original publication on 1816) supposed that elementary waves arising at every point along the arc of the wave front mutually interfere. Only based on this new assumption could the wave theory for the first time explain the rectilinear propagation and interference of light consistently (Silliman, 1974, pp.152-4).

In short, on the eve of the optical revolution, it is very difficult to compare the corpuscular theory and the wave theory in the aspect of solving empirical problems. Both of them could continue to expand their domains of solved empirical problems and also both had empirical difficulties on almost the same scale. Under such circumstances, the members of the optical community turned their attention to another aspect when they tried to appraise these two rival theories - their conceptual problems. Since the corpuscular theory was involved in more and more conceptual problems, the new generation of the optical community gradually became disappointed in this research orientation and turned to the wave theory.[4] Thus, it was the inferior status of the corpuscular

[4] Not only did Young, Lloyd, and Whewell pay attention to the particle theory's conceptual problems, other major wave theorists, such as Fresnel, Herschel, Airy, and Powell, also regarded the existence of conceptual problems as their primary reason for rejecting the particle theory.

theory in dealing with conceptual problems that constituted the primary cause of the optical revolution.

By analyzing the criteria of theory appraisal that the historical figures actually employed in their practice rather than solely basing our analysis on abstract philosophical principles, our reconstruction of the optical revolution shows us the important role that conceptual problems play in the process of scientific revolution. Ignoring the role of conceptual problems, Worrall fails to explain why the optical revolution could occur in the late 1820's to early 1830's. Also, limiting himself to empirical factors, Achinstein fails to expose the conceptual contribution to the revolution. Only when we consider the existence and the crucial effect of conceptual problems in the change of scientific theories can the optical revolution be interpreted and reconstructed more precisely and fully.

Our reconstruction of the optical revolution, especially the analyses of the conceptual problems that occur in the revolution, also indicates the defects of Buchdahl's, Toulmin's, and Laudan's work on conceptual problems. One of the defects consists in the fact that Buchdahl's, Toulmin's, and Laudan's categories of conceptual problems fail to cover every case which occurs in the revolution. For example, Buchdahl's categories fail to cover the conceptual problems that arise from Brewster's explanation of diffraction and from Laplace's "necessary condition". Toulmin's categories cannot include internal or explicative problems as those in Laplace's notion of "ellipsoidal construction" and Brewster's notion of "crystalline forces". Laudan's categories also fail to cover the conceptual problem which arises from Laplace's notion of "ellipsoidal construction". These incomplete categories of conceptual problems, on the one hand, will certainly handicap our work in reconstructing scientific change, and, on the other hand,

See Fresnel, (1866), p. 253-4; Herschel, (1830), p.475; Airy, (1833), p.419-24; Powell, (1855), p.132.

will also limit our understanding of the basic characteristics of conceptual problems. Therefore, a more comprehensive set of categories for conceptual problems is desirable for future studies, and it is to this task I proceed in the next chapter.

Chapter IV

ANALYSIS

The task of this chapter is to present a more comprehensive set of categories, which can not only cover more varied conceptual problems but reflect the basic characteristics of conceptual problems more correctly. In order to set up such a comprehensive set of categories, I will employ an historical method, that is, the categories for conceptual problems will be based on the summarization or generalization of historical cases, rather than on philosophical theories. Therefore, in this chapter I will first conduct a detailed analysis of some examples of conceptual problems presented in the last chapter. After discussing the similarities and differences among these examples, I plan to summarize the basic features of these conceptual problems, and to compare my summary with Buchdahl's, Toulmin's, and Laudan's opinions. Finally, I will present a more comprehensive set of categories for conceptual problems and give more historical examples to support this set of categories.

1. A detailed analysis of historical examples

In the last chapter, I already showed that none of Buchdahl's, Toulmin's, and Laudan's categories of conceptual problems can cover every case which occurs in the optical revolution and thereby none of them can uncover the similarities among these examples. In order to reveal the basic features of conceptual problems hidden in these historical examples, a more detailed analysis of these examples is needed. In this section, I will choose the following four examples for my detailed analysis, that is: Young's concept of "light", Brewster's explanation of diffraction by a non-gravitational "force", his explanation of double refraction by a "crystalline force", and Laplace's explanation of double refraction by an "ellipsoidal construction". The focus of this analysis is to expose the common features of these historical conceptual problems by examining how they arise.

i) Example 1: Young's concept of "light"

When Young explained the phenomena of diffraction and interference, he introduced a concept of "light" which is rather vague. He treated the propagation of light as consisting of rectilinear rays, but when the rays of light crossed he attributed a wave character to them. The introduction of this concept generates a conceptual problem which, in Buchdahl's categories, belongs to the explicative components. But why does Young's concept of "light" bring about a conceptual problem? And what exactly is the source of this conceptual problem?

Generally speaking, the purpose of introducing a concept is for certain applications, for example, answering questions or describing phenomena, etc. For a large class of cases, the meaning of a concept consists in its applications (cf. Wittgenstein, 1953, $43).

One class of application of a concept, which is important in science, is referential application. In order to apply a concept referentially, however, we first have to know what the concept refers to, or, what the referent of the concept exactly is. If a concept fails to satisfy this condition, it will be very difficult to apply it in any concrete case and, lacking application, the concept will thereby be regarded as meaningless. In the Young's case, the concept of "light" refers to two distinct objects - rays and waves. Since waves spread in all directions while rays only in one, the wave character of light is not compatible with the character of light's rectilinear propagation. Thus, there was an ambiguity about the referent of light. No one, probably except Young himself, knew what the concept of "light" exactly refers to. In this situation, the concept of "light" became hard to apply and a conceptual problem occurred. In summary, the conceptual problem in this case was generated in the process of the application of the concept, and the basic symptom of the conceptual problem is that the concept became meaningless because there was an ambiguity about its referent.

ii) Example 2: Brewster's non-gravitational "force"

When Brewster explained diffraction, he assumed that the force between particles of light does not depend on the mass of one of them. The concept of this non-gravitational "force" is not compatible with the Newtonian gravitation law and thereby creates an external conceptual problem in Laudan's or in Toulmin's sense. But how can an external conflict with other theories make a concept itself meaningless? If we do not consider the Newtonian law of gravitation, Brewster's concept is not problematic. It has its referent - attractive action - in the concrete case that Brewster discussed. However, the application of a concept requires not only the existence of an object as the concept's referent, but also an exact specification of the properties of the object. In some situations, even when the object which is supposed to be the referent of a concept exists, applications of the concept will still fail because the properties it designates to its referent are not appropriate. In this case, if we connect the concept with the law of gravitation, the properties of the referent become questionable. According to the law of gravitation, it is unacceptable to assign any property to the attractive force between two bodies that does not depend on the mass of one of them. Therefore, the conceptual problem here arises from the fact that the referent of the concept had been assigned a property that does not belong to it, given our prior knowledge of 'force'. More exactly, Brewster's concept of "force" is not applicable because, in the light of the law of gravitation, the properties of its referent are not identified appropriately.

iii) Example 3: Brewster's "crystalline force"

In his explanation of double refraction, Brewster introduced a concept of "crystalline force", which is rather vague and unclear, and can therefore be classified as an internal conceptual problem in Laudan's categories or an explicative conceptual problem in Buchdahl's categories. However, why does a vague concept create a conceptual problem? Again, when we analyze the process of applying a concept we can answer this question. Having an existing object as a referent and specifying an appropriate list of properties of this object are only part of the conditions for a concept's application. In order to apply a concept properly, we should follow certain application procedures. If we do not know what these procedures are, we will have difficulty in the process of applying the concept. In Brewster's case, there is no question about the existence of a "crystalline force". Brewster clearly identified the short-range force exerted by crystalline axes as the referent of "crystalline force" in the context of optics. However, he did not tell people how to apply this concept in concrete cases by indicating its application procedures. Specifically, he did not tell people how a crystalline force can be applied as an attractive factor with respect to certain angles of the crystalline axes and how it can be applied as a repulsive factor with respect to other angles. Therefore, the conceptual problem in this case is also generated in the process of concept application, and the basic feature of this conceptual problem is that the concept becomes meaningless because its does not have an appropriate application procedure.

iv) Example 4: Laplace's "ellipsoidal construction"

In order to explain the law of double refraction Laplace introduced a concept of "ellipsoidal construction" that has physical meaning in ordinary language and even in the scientific context of astronomy [5], but does not have any physical meaning in the appropriate scientific context of optics. When Young reviewed Laplace's paper, he pointed out that it was not satisfactory for Laplace to do so (cf. Young, 1809, p.228). The introduction of "ellipsoidal construction" brought about a conceptual problem which can be put into Buchdahl's explicative components. But what exactly is the problem in this case? In fact, the trouble pointed out by Young is also about the application procedure of the

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[5] According to Laplace, the phenomena of astronomy have "taken the form of the ellipsis" since the elliptic form depends on the law of gravitation (cf. Young, 1809, p.228).

concept. When Laplace applied the concept in astronomy, he followed a particular procedure which uses the concept referentially, but when he applied the same concept in optics, he followed a distinct procedure which uses the concept non-referentially. Laplace did not tell people how the concept can be applied referentially and how it can be applied non-referentially, and even people such as Young did not know how to apply the concept to other cases. Therefore, the basic feature of the conceptual problem in this case is also that the concept becomes meaningless because its does not have a specific application procedure.

2. A comparison of the cases

After examining four examples of conceptual problems in the optical revolution, now we can begin to reveal the basic characteristics of conceptual problems by summarizing the similarities and differences among these examples. In this section, I will focus my attention only to three basic features of conceptual problems, that is, the basis of conceptual problems, the sources of conceptual problems, and the primary symptom of conceptual problems.

i) The basis of conceptual problems

In the examples we examined above, it is clear that in the first and the last examples, the bases of the conceptual problems are single concepts - "light" and "ellipsoidal construction". In the other two examples, the bases of the conceptual problems are some groups of concepts, for example, the concept of "crystalline force" in the second example includes several single concepts such as "force", "crystalline axis", "attraction", and "repulsion", etc. Therefore, if we introduce a notion "conceptual structure" which refers to any relatively independent group of concepts or single concept, we can define such conceptual structures as the basis of conceptual problems, and conclude that conceptual problems are the characteristics of conceptual structures and have no existence independent of the conceptual structures which exhibit them.

Laudan also uses "conceptual structure" to describe the basis of conceptual problems, but he intends to identify "conceptual structure" with theory (Laudan, 1977, p.48). However, there are differences between a conceptual structure and a theory. A theory certainly embodies some conceptual structures, but there is no one-to-one corresponding relationship between a theory and a certain conceptual structure. Actually, a conceptual structure can give rise a number of different theories, and a theory can embody different conceptual structures at different times [6]. Thus, regarding theory as the basis of conceptual problems cannot help us to understand the question because it confuses two notions - conceptual structure and theory - which are fundamentally different.

ii) The sources of conceptual problems

What are the conditions under which conceptual problems may arise? This question can also be answered by summarizing the examples described above.

In the first example, that is, Young's concept of "light", the conceptual problems arise from the fact that, due to some internal defects, the conceptual structure does not

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6 For example, Newtonian mechanics can be regarded as embodying either Newton's concept of mass or Mach's concept of mass.

have a specific referent in the scientific context. In the second example, that is, Brewster's concept of non-gravitational "force", the conceptual problem arises because the conceptual structure does not have an appropriate list of properties for its referent, even though the existence of its referent is not questionable. And in the last two examples, that is, Brewster's concept of "crystalline force" and Laplace's "ellipsoidal construction", the conceptual problems arise because the conceptual structures do not have appropriate procedures for their applications. These are three conditions under which conceptual problems may occur. However, all of these three conditions occur actually in the process of concept application. More exactly, all of them are conditions for the successful and appropriate applications of any conceptual structure. Without identifying the referent of a conceptual structure, the appropriate list of properties of its referent, and its application procedure, it would be very difficult to apply this conceptual structure in any concrete case. Therefore, we can conclude that conceptual problems arise from the processes of concept application, especially in the processes of identifying the referent of the conceptual structure, of defining the set of properties of its referent, and of explicating the procedure of its application. Here I do not suggest that "meaning" and "reference" are identical, nor do I use these terms in any special technical sense. In those scientific contexts where a concept is intended to have a referent, if it can be shown that the referent does not exist, the concept will be regarded as meaningless.

The examples of conceptual problem examined above also indicate that conceptual problems can occur in two distinct situations. In the first, conceptual problems may arise entirely from the internal defects of a conceptual structure, such as lack of an appropriate referent, or an appropriate list of referent's properties, or an application procedure. The conceptual problems in the first and the last two examples belong to this type of difficulty which can be called internal conceptual problems. Second, conceptual problems may also occur because a conceptual structure conflicts with other conceptual structures (or theories, or metaphysical and methodological principles). The conceptual problems in the second example above belongs to this type of difficulty which can be called external conceptual problems.

In external conceptual problems, it seems that the difficulties are not created by any internal defect of conceptual structures themselves, but by the external conflicts between the conceptual structure and other theories or beliefs. Based on this, Laudan argues that such external conflict or tension constitutes conceptual problems (Laudan, 1977, p.51). However, why can an external conflict make a conceptual structure troublesome? Laudan does not go on to answer this question. In fact, the reason that an external conflict can make a conceptual structure problematic is because, if we accept those theories or beliefs, the application of the conceptual structure about which we are concerned will be impossible, probably due to the rejection of its referent, or of the properties of its referent, or of its application procedure. That is to say, an external conflict can make the application processes of a conceptual structure problematic. We can conclude that external conceptual problems are also generated by the internal features of a conceptual structure which only appear problematic in the light of some well-accepted conceptual structures.

iii) The primary symptom of conceptual problems

In the four examples examined in the last section, all of the conceptual problems arise from the processes of concept application. On the one hand, the failures in applying a conceptual structure, without exception, generate a variety of conceptual problems. And on the other hand, if a conceptual structure fails to be applied properly, it is evident that this conceptual structure will be meaningless, because the meaning of a conceptual structure lies fundamentally in its application. Therefore, it is reasonable to regard "meaninglessness" as a primary symptom of conceptual problems. Based on this understanding, we define conceptual problems as questions about the meaning of conceptual structures which have been devised for certain applications, and conclude that a conceptual problem only occurs when a conceptual structure, due to its internal defects or to the conflicts with other conceptual structures (or theories, beliefs etc.), becomes meaningless.

Obviously, our generalization of the primary symptom of conceptual problems is distinct from that provided by Laudan, who intends to reduce the primary symptom of conceptual problems to some kind of logical difficulties. However, Laudan's interpretation of the primary symptom of conceptual problems has its difficulties. Even within Laudan's categories of conceptual problems, not every case can be regarded as a logical difficulty. For example, the conflicts with methodological principles or metaphysical beliefs, which are regarded by Laudan as an important part of external conceptual problems, are not logical difficulties. Therefore, we had better understand logical difficulties as only representing a small part of conceptual problems. Since the consequence of some logical difficulties is also a meaningless conceptual structure, our definition of the primary symptom of conceptual problems is certainly more general and thereby can become a reasonable basis for a more comprehensive set of categories for conceptual problems.

3. A more comprehensive set of categories for conceptual problems

After summarizing the basic characteristics of conceptual problems, especially the basis, the sources, and the primary symptom of conceptual problems, we are able to present a more comprehensive set of categories for conceptual problems which is supposed to cover a greater range of cases.

Based on the understanding that a conceptual problem is a question about the meaning of a conceptual structure in its applications, our new categories classify conceptual problems by identifying a variety of conditions under which conceptual structures have difficulties in their applications and thereby become meaningless. Following this principle, conceptual problems are divided into two distinct categories:

First, there are internal conceptual problems which arise when a conceptual structure fails in its application because of difficulties about the existence of its referent, or about the properties of its referent, or about its application procedure.

Secondly, there are external conceptual problems which arise when a conceptual structure has difficulties in its application because of its conflicts with other conceptual structures (or theories, beliefs). These difficulties again fall into three types involving the existence of referent, the properties of referent, and application procedures, respectively.

i) Internal conceptual problems

According to the difficulties that occur in the processes of concept application, internal conceptual problems can in turn be divided into three sub-categories: the conceptual problems about the existence of referent, the conceptual problems about the properties of referent, and the conceptual problems about application procedure.

(a) problems about the existence of referent

An extreme, though by no means the most frequent, type of internal conceptual problems about the existence of referent is that a conceptual structure does not have a referent at all. For instance, in order to explain the cause of human cancer, Huebner put forward a theory suggesting that the existence and derepression of "oncogene" in the cells of human body cause the formation of cancer-inducing viruses. Here "oncogene" is the key concept in Huebner's theory. But what is the referent of it? Huebner failed to give a satisfactory answer to this question. In the relevant biomedical community, no one knew what the word "oncogene" exactly meant and where an "oncogene" could be identified. Due to these difficulties, many biologists believed that Huebner's theory was not formulated well enough to be tested, or to be accepted (cf. Studer & Chubin, 1980, p.114).

A more common type of internal conceptual problem about the existence of referent arises when a conceptual structure does not have a referent in an appropriate context. If a scientific concept merely has a referent in ordinary language context, or in an irrelevant scientific language context, it will still generate conceptual problems. Also, a conceptual problem about the existence of referent may arise because of the ambiguous identification of referent. In any specific context, a meaningful conceptual structure should have only one referent. If in the same context, a conceptual structure has several referents, no matter whether they are inconsistent or merely distinct, this conceptual structure will not be regarded as having an appropriate referent. When Faraday used the Newtonian concept "space" to account for the communication of electric action, for instance, he found that "space" has two different referents: It refers to a non-conductor in non-conducting bodies, and a conductor in conducting bodies (Faraday, 1839, Vol.2, p.287). This ambiguity of the referent brought about a conceptual problem that finally led Faraday to replace the concept "space" with his new concept "field". Another example of this kind of conceptual problems can be found in Young's concept of "light", which sometimes refers to rectilinear rays and sometimes refers to waves and brings about an ambiguity of the referent of "light" (for detailed analysis, see pp.35-36).

(b) problems about the properties of referent

In addition to the existence of referent, there is another condition for the application of a conceptual structure, that is, every conceptual structure should identify an appropriate set of properties for its referent. If a conceptual structure fails to specify the properties of its referent, its application in concrete cases will become almost impossible. More commonly, even though a conceptual structure has specified the properties of its referent, the specification may be inaccurate so that the conceptual structure cannot be applied to every case in which it should have successful application. In this case, the conceptual structure may also be regarded as meaningless. Maxwell's concept "electricity" is a good example to illustrate such a problem. In the nineteenth century, the properties of the referent of "electricity" was clear, which included every electric phenomena occurring in conductive and dielectric bodies. In Maxwell's theory, however, the properties of "electricity" are defined only as some kind of polarization in dielectric bodies. Because conductors are incapable of sustaining this polarization, the concept of "electricity" in Maxwell's theory cannot be applied to the cases of conducting bodies, which clearly belong to the domain in which the concept is supposed to be applied (cf. Thomson, 1885, pp.125-6). This narrow specification of properties brought about a conceptual problem and actually became an obstacle to the acceptance of Maxwell's theory.

(c) problems about application procedure

Another necessary condition for the application of a conceptual structure consists in the existence of a sound application procedure. When we apply a conceptual structure, we should follow a certain application procedure, which indicates how the conceptual structure is connected, step by step, to concrete cases. If we cannot identify an application procedure or the procedure we follow is unsound, we will be unable to apply the conceptual structure.

One common sort of conceptual problems about application procedure arises when the application procedure of a conceptual structure is so vague that no one can really follow it. The difficulties arising from Brewster's concept of "crystalline force" and Laplace's concept of "ellipsoidal construction" are good examples of this sort of conceptual problems (for detailed analysis, see pp.37-39).

Another sort of conceptual problems about application procedure arises from the difficulty that the application procedure of a conceptual structure involves some formal or informal fallacies. An extreme case is that the application procedure is logically circular. For instance, in order to eliminate the difficulty created by Newtonian concept of "action-at-a-distance", Faraday put forward a new concept - "contiguant particle".

When the concept of "contiguant particle" is applied, however, the application follows a circular procedure: some kind of short range action-at-a-distance is still necessary for the application which is supposed to show that the existence of action-at-a-distance is impossible (cf. Hare, 1840). This circularity brought about a conceptual problem that finally forced Faraday to give up his concept of "contiguant particle".

ii) External conceptual problems

External conceptual problems are the difficulties which occur when a conceptual structure is connected with other conceptual structures (or theories, or metaphysical and methodological principles) which are regarded as more acceptable. As I already pointed out in the last section, however, external conceptual problems also occur in the processes of concept application. More exactly, external conceptual problems arise only because, in the light of already accepted theories, the application of a conceptual structure becomes suspect. Therefore, external conceptual problems can also be divided into the following subcategories corresponding to the conditions of concept application.

(a) problems about the existence of referent

One kind of external conceptual problems about the existence of referent arises when the initial relationship of a conceptual structure with its referent changes if we accept a well-accepted conceptual structure or theory. More precisely, if a conceptual structure's initial referent is disallowed in the light of an already accepted conceptual structure (or theory), the conceptual structure will become meaningless. For example, in the "caloric" theory of heat provided by Lavoisier, "caloric" is a special kind of imponderable fluid, which is the substance of heat. Temperature was regarded as the referent of the "moving power" of the flow of "caloric". According to the kinetic theory of heat developed in the nineteenth century, however, heat is not regarded as an independent substance but as consisting in a motion of the particles constituting bodies, and temperature is no longer a moving power of "caloric" but the measure of the "living force" (kinetic energy) of the motion of the particles. In the view of kinetic theory, which was popularly accepted in the nineteenth century, heat refers to the motion of particles but not "caloric", and temperature refers to the kinetic energy of the motion of particles but not the moving power of the flow of "caloric". In this new theoretical context, therefore, "caloric" loses its initial referent and becomes meaningless (cf. Harman, 1982, 48-51).

Another kind of such external conceptual problems occurs when the existence of a conceptual structure's initial referent becomes impossible or even unintelligible in the light of an already accepted theory. An example of this kind of conceptual problems can be found in Newton's concept of "gravitation". In the explications made by Newton, "gravitation" is an attractive force that acts at a distance. This explication of "gravitation", however, was incompatible with a contemporary ontological principle, which asserted that bodies can only exert force by contact. To the people who accepted this ontological principle, the existence of the gravitational force which can act on the earth through several million miles of empty space is "inconceivable". For example, following this principle, Locke objected that gravitational attraction "cannot be conceived to be the natural consequence of that essence [namely, essence of matter]" (cf. Buchdahl, 1970, p.215). Therefore, if we accept the ontological principle, "gravitation" is just unintelligible, because it lacks a referent.

(b) problems about the properties of referent

One extreme case of external conceptual problems about the properties of referent occurs when the referent of a conceptual structure is assigned properties, which are incompatible with its initial properties, by a well-accepted conceptual structure (or theory). In principle, it is impossible to assign two incompatible properties to one object. Therefore, in the light of the well-accepted conceptual structure (or theory), the initial properties of the referent are unacceptable and the initial applications of the conceptual structure are thereby problematic. The trouble in Laplace's concept of "force in extraordinary rays" is a typical example of this kind of conceptual problems. When Laplace deduced the law of double refraction, he ascribed a special property to the "force in extraordinary rays": This force is a function of an object's direction of motion. According to the Newtonian theory of the field of central force, however, the force that acts on extraordinary rays should have a totally incompatible property: It is a function of an object's position. Since it is impossible for a central force to be both a function of an object's direction and a function of an object's position, for those who accepted Newtonian mechanics, Laplace's specification of the property of the force in extraordinary rays is totally wrong and his application of this concept is thereby unacceptable. Another example of this kind of conceptual problems can be found in Brewster's concept of non-gravitational "force", in which the property that Brewster assigned to the concept's referent, in the light of the Newtonian law of gravitation, is entirely wrong (for detailed analysis, see pp.36-37).

More commonly the external conceptual problems about the properties of referent arise when the initial specification of the properties is regarded, in the light of a well-accepted conceptual structure or theory, as inaccurate. Sometimes the inaccuracy results from the fact that the initial list of the properties is too wide. In other words, the initial list of properties includes something that does not belong to the object. And sometimes the inaccuracy results from too narrow identification. That is to say, some important properties are not included in the list. For example, when Arago explained the observed constant velocity of light, he assumed that our eyes have a special sensibility which only senses the light particles with a particular velocity. Here, Arago assigned a special property to our eyes: Our eyes can only sense one particular sort of light particles. According to the well-accepted knowledge of vision in the nineteenth century, however, our eyes can sense a variety of particles of light with very different velocities. In the view of Lloyd, therefore, Arago's specification of the property of eyes is too narrow and "does not appear to be easily reconciled with any hypothesis which we are able to frame respecting the nature of vision" (Lloyd, 1834, p.25). This difficulty in specifying the property finally created a conceptual problem and made Arago's explanation unacceptable.

(c) problems about application procedure

In some special situations, the initial application procedure of a conceptual structure will become unacceptable or even unintelligible because the procedure conflicts with other well-accepted conceptual structures or theories, and thereby generate an external conceptual problem about application procedure.

One example of such conceptual problems consists in the particle explanation of diffraction at an aperture. In order to explain the phenomena of diffraction, particle theorists introduced an auxiliary hypothesis which supposes that bodies of different forms and different refractive power should have equal power of inflection. In this explanation, the concept of "the force of inflection" is applied to different objects through a procedure which does not regard the differences in the form and refractive power of the objects as significant. This application procedure, however, is not compatible with a metaphysical axiom that different causes should have different effects. Therefore, for those who accepted the metaphysical axiom, the particle explanation of diffraction is unacceptable because it involves an unintelligible application procedure.

Another example of external conceptual problems about application procedure can be found in Ptolemy's concept of "planetary radius". When the concept of "planetary radius" is applied to concrete cases in Ptolemy's astronomy, the application procedures are not the same in every cases. The determinations of the radii of Mercury and Venus, for example, are entirely different from other planets. For a long period, since astronomy had been regarded as mere a collection of devices for saving phenomena, there was nothing wrong with using different application procedures in different cases. But in the sixteenth century, a methodological principle became popular, which required uniform and systematic methods in solving problems within a domain. In this new methodological context, the Ptolemaic application procedures for "planetary radius", which are not uniform, became unacceptable. The recognition of these problematic application procedures and the consequent conceptual problems was an important factor that encouraged Copernicus's successors to overthrow the astronomy of Ptolemy (cf, Curd, 1982 & Price, 1976).

Chapter V

CONCLUSION

Based on a generalization of a variety of historical cases of conceptual problems, especially on a detailed analysis of the conceptual problems which occurred in the optical revolution, a more profound understanding of conceptual problems is obtained. This new understanding of conceptual problems includes the following definitions of conceptual problems: First, conceptual problems are the characteristics of conceptual structures and have no existence independent of the conceptual structures which exhibit them. In other words, conceptual structures are the basis of conceptual problems. Second, the sources of conceptual problems are the processes of concept application, especially in the processes of identifying the existence of a conceptual structure's referent, of specifying the properties of its referent, and of explicating the procedure of its applications. Third, the primary symptom of conceptual problem is that a conceptual structure becomes meaningless. In short, according to this new understanding, a conceptual problem is a difficulty about the meaning of a conceptual structure in its applications.

Following this new understanding, I have presented a more comprehensive set of categories for conceptual problems. In this new set of categories, conceptual problems are divided into two distinct groups. First, there are internal conceptual problems which arise when a conceptual structure has difficulties in its applications because of its internal defect about the existence of its referent, or about the properties of its referent, or about its application procedure. Second, there are external conceptual problems which arise because, in the light of other conceptual structures or theories that are well-accepted, the application of a conceptual structure is objectionable. These objections may again focus on the existence of referent, the properties of referent, or the application procedure for the conceptual structure.

It is evident that the new definitions and categories of conceptual problems provided by this paper can overcome a series of defects in Buchdahl's, Toulmin's, and Laudan's work on conceptual problems.

For example, since Laudan defines theory as the basis and logical difficulties as the symptom of conceptual problems, the major defects of his work are that his definition of conceptual problems fails to expose the fundamental feature of conceptual problem and his categories can only cover those conceptual problems which involve some kind of logical difficulties. By recognizing the differences between a conceptual structure and a theory, and defining meaninglessness as the primary symptom of conceptual problems, my new definitions reveal more profound features of conceptual problems, belonging to a conceptual structure rather than to a theory, and my new categories cover a wider range of historical cases, in which all of Laudan's categories are included.

In Buchdahl's and Toulmin's work on conceptual problems, the major defects are that they do not present a complete and systematic set of categories for conceptual problems, although they indeed have some adequate understandings of conceptual problems. For example, Toulmin's categories do not cover the external conceptual probems that arise from the conflicts with methodological principles and entirely ignore the internal problems about concept's metaphysical foundation; and in Buchdahl's categories, there is no place for those external conceptual problems which arise from the conflicts with other conceptual structures or scientific theories rather than metaphysical principles. In my categories for conceptual problems, all of the categories that Buchdahl and Toulmin provide can be easily included. A part of Toulmin's categories (the first two types) can be regarded as the internal conceptual problems about application procedures, and the rest belongs to some kind of external conceptual problems. Buchdahl's explicative components can be put into the category of internal conceptual problems, and his architectonic components belong to a part of external conceptual problems (the problems arise from the conflicts with metaphysical and methodological principles).

The conclusion of this thesis cannot be regarded as a final statement in the research on conceptual problems. I have only discussed some basic features of conceptual problems in a limited number of historical cases, and focused on how these conceptual problems arise. Certainly these are not the whole story of conceptual problems. There are several questions which are important for understanding conceptual problems but ignored in this paper. For example, What are the relationships between conceptual problems and empirical problems? What is the rationale of adopting such non-empirical criteria as conceptual problems in theory appraisal? And how, if at all, can we devise a measurable criterion to compare the abilities of competing theories in solving conceptual problems? Pursuing the answers to these questions is certainly desirable for future studies in the field of conceptual problems.

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