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Author(s): Xiang Chen
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THOMAS KUHN'S LATEST NOTION OF INCOMMENSURABILITY

XIANG CHEN

SUMMARY. To correct the misconception that incommensurability implies incomparability, Kuhn lately develops a new interpretation of incommensurability. This includes a linguistic theory of scientific revolutions (the theory of kinds), a cognitive exploration of the language learning process (the analogy of bilingualism), and an epistemological discussion on the rationality of scientific development (the evolutionary epistemology). My focus in this paper is to review Kuhn's effort in eliminating relativism, highlighting both the insights and the difficulties of his new version of incommensurability . Finally I suggest that some of Kuhn's difficulties can be overcome by adopting a concept of rationality that filly appreciates the important role of instruments in the development of science.

Key words: Kuhn, incommensurability, instruments

One of most controversial themes in Kuhn's philosophy of science is his thesis of incommensurability, which, in its original version, claims that scientists are living in a different world after a scientific revolution. Many of Kuhn's readers thus conclude that Kuhn's thesis implies incomparability between paradigms, and many philosophers charge Kuhn with relativism. However, Kuhn repeatedly claims that these charges represent misunderstandings of his thesis, which in effect allows rational comparisons of successive theories or paradigms and does not imply relativism (Kuhn, 1983, p. 670; 1989a, p. 23; 1991a, p. 3). To correct these impressions, Kuhn recently has developed a new interpretation of incommensurability. This includes a linguistic theory of scientific revolutions (the theory of kinds), a cognitive exploration of the language learning process (the analogy of bilingualism), and an epistemological discussion on the rationality of scientific development (the evolutionary epistemology).

The purpose of this paper is to examine Kuhn's latest notion of incommensurability, which emerged mainly in a dozen of articles and manuscripts Kuhn wrote during the late 1980s and the early 1900s.[1] I will review Kuhn's theory of kinds, his analogy of bilingualism, and his evolu-

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tionary epistemology one by one. While I introduce Kuhn's latest notion of incommensurability, I will also evaluate his efforts in eliminating relativism, highlighting both his insights and difficulties. Finally, I will explore the role of instruments in establishing taxonomies and learning concepts, and suggest that some of Kuhn's difficulties can be overcome by adopting a concept of rationality that fully appreciates the important role of instruments in science.

1. THE THEORY OF KINDS

In *The Structure of Scientific Revolutions*, Kuhn uses Gestalt shifts as an analogy to illustrate his incommensurability theses: scientists see things in an entirely different way after a revolution, as if they were wearing glasses with inverting lenses (Kuhn, 1970, p. 122). The incommensurability theses then implies that scientists will experience difficulties in evaluating rival paradigms, because there are no shared standards and shared concepts among them.

To avoid criticisms of relativism, Kuhn later modifies his position. He drops the Gestalt analogy, abandoning the implied perceptual interpretation of the thesis. Kuhn then develops a metaphor based on language: during scientific revolutions, scientists experience translation difficulties when they discuss concepts from a different paradigm, as if they were dealing with a foreign language. Incommensurability thus is confined to meaning change of concepts, and becomes a sort of untranslatability (Ibid., p. 198).

Kuhn's next revision is to narrow the scope affected by revolutions. In the early 1980s, he introduced a notion of "local incommensurability", claiming that "[during a scientific revolution], most of the terms common to the two theories function the same way in both; their translation is simply homophonic. Only for a small subgroup of (usually interdefined) terms and for sentences containing them do problems of translatability arise" (Kuhn, 1983, pp. 670–71). Incommensurability thus becomes untranslatability caused by the meaning change of a small group of terms. With this revision, Kuhn hopes that his thesis no longer implies incomparability of rival paradigms, because there always exist unchanged concepts between rival paradigms during revolutions.

Continuing this direction, Kuhn recently has further limited the scope of incommensurability by introducing a theory of kinds. He says that "[b]y now, however, the language metaphor seems to me far too inclusive. To the extent that I'm concerned with language and with meanings at all, ... it is with the meanings of a restricted class of terms. Roughly speaking, they are taxonomic terms or kind terms, a widespread category that includes natural kinds, artificial kinds, social kinds, and probably others" (Kuhn, 1991a, p. 4).[2]

According to Kuhn, these kind terms have two essential properties. The first one is called the kind-label condition. In English kind terms are primarily nouns that take the indefinite article, either by themselves (count nouns) or combined with other kind terms in phrases (mass nouns). We can define kind terms in terms of this lexical characteristic of taking the indefinite article.

Another important property of kind terms is conceptual, regarding the relations between kind terms and their referents. These relations are governed by a non-overlap principle. Kuhn notes that "no two kind terms, no two terms with the kind label, may overlap in their referents unless they are related as species to genus" (Ibid.). For example, there are no gold rings that are also silver rings, but there are red things that are also beautiful. If two kinds terms do have overlapping referents in a speech community, communication failures are inevitable: people simple do not know how to name those referents in the overlapping region.

However, there are exceptions to this non-overlap principle. For example, Hacking points out that both "poison" and "mineral" are kind terms, but overlap in such referents as arsenic (Hacking, 1993, pp. 286–87). To solve this sort of problem, Kuhn later restates the non-overlap principle as the follows: "only terms which belong to the same contrast set are prohibited from overlapping in membership. 'Male' and 'horse' may overlap but not 'horse' and 'cow'" (Kuhn, 1993, p. 319). Here, "the same contrast set" refers to a group of kind terms under the same immediate superordinate category. Thus, "horse" and "cow" cannot have overlapping referents because they are subcategories of "farm animal", but "poison" and "mineral" can have overlapping references because they belong to different contrast sets.

The non-overlap principle is thus built upon the interconnections among kind terms, and reflects the lexical structure of language. This lexical structure determines that kind terms cannot be defined individually. "Most kind terms must be learned as members of one or another contrast set" (Ibid. p. 317); for example, to define the term "liquid", one most also understand the terms "solid" and "gas", and make sure that there is no overlap in referents among these terms. For those whose contrast sets cannot be identified by daily experiences, usually theoretical terms such as "mass" in Newtonian mechanics, one must define them by theoretical laws, which connect "mass" with other kind terms such as "force", "acceleration", or "distance".[3]

The interconnections among kind terms, or, the lexical taxonomy as a whole, guarantees that members from a speech community define kind terms in the same way, although they may develop dissimilar exemplars for some kind terms' referents or uses due to individual preferences. Because they share the same taxonomy, the dissimilar exemplars among the members of a speech community are compatible, in the sense that some members may know new referents or novel uses of a kind term that others do not, but they can learn more about these new things from each others and eventually agree with each other (Ibid.).

However, between people from different communities, dissimilar exemplars can be incompatible, because there is not a shared taxonomy. Individuals may define the same kind terms by different lexical connections, and may develop irreconcilable exemplars, so that they refer a kind term to referents or apply it to situations that other categorically denies. In these cases, the non-overlap principle is violated, and communication between these two communities fails. This communication failure regarding the meaning of kind terms is severe because the difference between them cannot be rationally adjudicated.

With this theory of kinds, Kuhn redraws the picture of scientific revolutions. Since the interconnections among kind terms form a lexical taxonomy, scientific revolutions, which now are limited to the meaning change of kind terms, become taxonomic changes. A scientific revolution produces a new lexical taxonomy, in which some kind terms refer to new referents that overlap with those denoted by some old kind terms. Therefore, incommensurability does not result merely from translation failures of individual concepts. The prerequisite for full translatability between two taxonomies is not shared features of individual concepts, but a shared lexical structure (Kuhn, 1990b, p. 7). Scientists from rival paradigms face incommensurability because they construct different lexical taxonomies and thereby classify the world in different ways.

With this new picture of revolutions, Kuhn refines the concept of holism that always characterizes his philosophy of science. Giving up the global holism developed in *The Structure*, Kuhn now emphasizes the localist features of revolutions. Instead of discussing such a global entity as a paradigm or a disciplinary matrix, which covers everything from methodology to epistemology, and to ontology, he focuses on a very limited class of entities – kind terms. The meaning change of kind terms, however, "is an adjustment not only of criteria relevant to categorization, but also of the way in which given objects and situations are distributed among preexisting categories. Since such redistribution always involves more than one category and since those categories are interdefined, this sort of alteration is necessarily holistic" (Kuhn, 1981, p. 20). Thus, meaning change of kind terms captures the revolutionary features of paradigm shifts. In particular, meaning change of kind terms requires accompanying revisions of the whole lexical taxonomy, and may cause incommensurability between different scientific communities. On the other hand, because meaning change happens only in a very restricted class, there are many terms that preserve their meanings during a revolution and provide a possible common ground for rational comparisons. With this localization attempt, Kuhn hopes that he can eliminate relativism from the incommensurability thesis.

However, even if meaning change is localized in a limited number of kind terms, rational comparisons between rival paradigms are not always possible. Not all kind terms have the same status in the lexical taxonomy: some are central because they stipulate the meaning of others, but some are merely peripheral. If meaning change occurs in a limited number of peripheral kind terms, rational comparisons may be possible because of a common ground in central kind terms. But it would be totally different if meaning change happens in some central kind terms, such as "planet" in Ptolemaic astronomy or "mass" in Newtonian physics, which were in the hard cores of these theoretical frameworks. If scientists from rival paradigms cannot define these central kind terms in a compatible way, how can they understand each other? It seems that this kind of meaning change, although it is local, inevitably results in communication breakdown between the communities. If so, how can rational comparisons between these rival paradigms be possible? Thus, localized meaning change still implies incomparability.

2. THE ANALOGY OF BILINGUALISM

In his early writings, Kuhn always connected incommensurability with failures of translation, because, if translation fails, no individual can "hold both theories in mind together and compare them point to point with each other and with nature" (Kuhn, 1977, p. 338). But in the early 1980s, Kuhn found that translation in fact involves two distinguishable components: a process of technical translation and a process of interpretation. Translation in the technical sense consists exclusively in replacements of words (no necessarily one-to-one) in the foreign language by those in the native. Interpretation, however, is a learning process, in which language learners try to make sense of a significant portion of the foreign language by relating it to its linguistic context, but not to their native language (Kuhn, 1983, pp. 672–73). Incommensurability is just related to untranslatability in the technical sense. That two theories are incommensurable implies that their concepts cannot be mutually translated through word replacements, but the proponents of one can learn the theory of their rival by interpretation.[4]

In the late 1980s, Kuhn further specified the meaning of untranslatability with the help of his theory of kinds. In Kuhn's refined picture of scientific revolutions, meaning change in kind terms inevitably causes "a sort of untranslatability, located to one or another area in which two lexical taxonomies differ" (Kuhn, 1991a, p. 5). This kind of untranslatability results from difficulties in mapping a foreign taxonomy with the native one. A foreign term is untranslatable not because we cannot find its referents in its linguistic context, but because we cannot find a native term with referents that do not overlap those of the foreign one. Translation failures are thus caused by violations of the non-overlap principle.

This new specification of untranslatability entails that a failure in translation does not cause a total collapse in understanding the foreign language. We may not be able to translate a term from a foreign language to English, but we can comprehend it through a process of interpretation, learning the meaning of a foreign term by directly identifying their referents in its linguistic context without referring to our native language. Thus, untranslatability does not entail incomprehensibility. Similarly, comprehensibility does not guarantee translatability either. An example is an English term "mat": it is comprehensible by every Frenchmen who knows English, but not translatable into French in the technical sense, because it and those related French terms overlap in their referents (Kuhn, 1990b, p. 3).

Kuhn thus virtually gives up the translator analogy he developed in the 1970s, which regards translation as the main channel for communication between rival paradigms. He instead introduces an analogy of bilingualism to illustrate the cognitive relationships between two successive paradigms. According to Kuhn, "the process which permits understanding produces bilinguals, not translators . . ." (Kuhn, 1991a, p. 5). The learning process of bilinguals has a couple very important features. First, when bilinguals acquire a second language, they need not be able to translate every term to their native language. Bilinguals can directly acquire a second language without mediation by the first language, so understanding without translation is possible. Second, what they practice is a process of language add-on: they acquire a new lexical taxonomy that is separate from their native one, and there is not a larger lexical taxonomy that incorporates the newly acquired taxonomy with the native one. By joining two different languages together, bilinguals can enrich their native taxonomy by adding to it sets of terms from the newly acquired taxonomy (Kuhn, 1990a, p. 318; 1990b, p. 8).

However, this kind of enrichment is peculiar, Kuhn notes. "It is like the enrichment that gives philosophers an alternative set of terms for describing emeralds: not 'blue', 'green', and the traditional roster of color terms, but 'grue', 'bleen', and the names of the other occupants of the corresponding spectrum. One set of terms is projectible, supports induction, the other not" (Kuhn, 1990a, p. 308). Therefore, bilingualism has its price. Differing from translators, bilinguals frequently report that there are things they can express in one language but not in the other. The terms they learn in this way may not be projectible outside their own lexical context, nor may they be translated into the native language without violations of the non-overlap principle.

According to Kuhn, the learning process of bilinguals is in many aspects parallel to those of historians and scientists. Similar to bilinguals, both historians and scientists can acquire these unfamiliar terms without translating them into either contemporary vocabulary or concepts used in their own scientific community. Also similar to bilinguals, historians and scientists achieve a lexical add-on in this process, attaching two independent linguistic systems together. But this linguistic add-on permits understanding of the past or of a rival paradigm, as long as historians or scientists remember which set of terms is being used in their discourse (Ibid.).

With this analogy of bilingualism, Kuhn is able to separate translation from understanding. Failures in translation now no longer imply disability in understanding, because we can directly acquire a foreign language without mediation by the native one. The separation of these two different issues has a very important implication to the thesis of incommensurability. Even if untranslatability occurs, either in a restricted set of kind terms or at a global level, we can still understand the meanings of these terms by a process of learning parallel to bilingualism. The ability to learn new terms from a foreign taxonomy without referring to the native one, according to Kuhn, guarantees that rational comparisons in theory choice can be done even when two theories are incommensurable. Thus, meaning change and the related untranslatability does not entail incomparability, nor does incommensurability involve relativism.

With the analogy of bilingualism, Kuhn convincingly reveals the difference between translation and understanding. However, this bilingual analogy, together with the theory of kinds, still does not eliminate relativism successfully. One problem is about the differences between understanding two languages and comparing them rationally. Kuhn seems to assume that our understanding of different languages or rival taxonomies naturally endows us with the ability to rationally compare them. But there are essential differences between understanding and comparison: the former is built upon a relation between language learners and language, while the latter requires a relation between different linguistic systems against certain evaluation standards.[5] The ability to learn a new language does not always ensure the possibility to make a rational judgment of it, unless we are certain that common standards have been adopted by both sides.

To illustrate the differences between understanding and comparison, consider the following analogy. Two persons, a Chinese native and a British native, try to decide which language, Chinese or English, is better. Both of them are bilinguals – the Chinese understands English quite well and the Briton can speak fluent Chinese. According to Kuhn, they should be able to make a rational comparison in their language choice. But this is not always the case, because they may adopt different standards for the evaluation. The Chinese may believe that, say, "information density" (how much information we can put in a unit of communication medium, such as sheep skin, paper or computer screen) should be the standard, and with this standard, Chinese is better than English, because one page of Chinese is usually translated into more than one page of English. However, the Briton may insist that "I/O speed" (how fast we can enter and retrieve information) should be the standard, and English is definitely better than Chinese because of the use of standardized keyboards. Here, these two bilinguals cannot have a rational judgment in their language choice, although they fully understand each other's language.

The moral of this analogy is important, especially when we consider the differences between the learning process of historians and of scientists. Kuhn admits that comparisons stemming from the process of lexical add-on are very peculiar. In this kind of comparison or evaluation, "what is then being judged is the relative success of two whole systems in pursuing an almost stable set of scientific goals . . ." (Kuhn, 1989a, p. 24). This implies that rational comparisons between these two taxonomies are possible under a very special condition, that is, when the evaluators happen to share a unique set of standards. So learning a new taxonomy by lexical add-on may help historians achieve rational evaluations of historical theories, because they, as spectators, are able to assign a unique set of standards in their projects according to their historiographies. But the same approach does not ensure that rational evaluations of rival paradigms are always possible for scientists. As participants, scientists from rival paradigms usually have different understandings of the goals of science and frequently have conflicting interests in the development of science. It is very unusual that scientists from rival paradigms happen to adopt the same evaluation standards. Thus, Kuhn's attempt to eliminate relativism from his incommensurability theses may be successful only in a limited case: the learning process of historical texts. For scientists who are polarized by rival paradigms, however, incommensurability may still imply incomparability.[6]

3. AN EVOLUTIONARY EPISTEMOLOGY

Kuhn's latest strike to eliminate relativism is to revise the evaluation standards for the development of science. To elaborate these new standards, he develops an evolutionary epistemology, which is primarily built upon an analogy between scientific development and biological evolution.

In *The Structure*, Kuhn already used an analogy to biological evolution to illustrate scientific revolutions: scientific development is parallel to biological evolution in the sense that both are products of competition and selection. So scientific development is a process driven from behind, not pulled from ahead to achieve a fixed goal (Kuhn, 1970, pp. 171–72).

Recently, Kuhn further explicates this analogy, revealing more similarities between scientific development and biological evolution. First, according to Kuhn, the relation of community members to the community in science is also parallel to the relation of individual organisms to the species. In biological evolution, individual organisms are characterized not only by their own gene sets, but also by the gene pool of the whole species. The moral of this parallel is that science is intrinsically a community activity, and that the traditional view of science as a one-person game is a harmful mistake (Kuhn, 1993, p. 329).[7] Second, both scientific development and biological evolution have the same pattern of growth in the form of an evolutionary tree. Kuhn holds that the pattern of knowledge growth is "the apparently inexorable (albeit ultimately self-limiting) growth in the number of distinct human practices or specialties over the course of human history" (Kuhn, 1992, p. 15). Proliferation of specialized disciplines is the key feature of scientific progress. Third, both scientific development and biological evolution produce isolated units in the process of their growth. In the biological case, it is a reproductively isolated population with members having difficulties in breeding with members from other populations. In the scientific case, it is a community of intercommunicating specialists who share the same taxonomy and have problems in communicating with people from other communities (Kuhn, 1991a, p. 8). Incommensurability is inevitable to the development of science.

With this refined analogy to biological evolution, Kuhn proposes an evolutionary epistemology to specify the evaluation standards for scientific development. The key of this new epistemology is to emphasize the essential differences between the rationality of belief and the rationality of incremental change of belief. The traditional epistemology supposes that the rationality of belief can only be justified by objective observation, independent of all other beliefs. "From the historical perspective, however, where change of belief is what's at issue, the *rationality* of the conclusions requires only that the observations invoked be neutral for, or shared by, the members of the group making the decision, and for them only at the time the decision is being made" (Kuhn, 1992, p. 11; original emphasis). Thus, the key idea of the traditional epistemology, a correspondence theory of truth that evaluates beliefs in terms of their reflection of a mind-independent world, is inappropriate to the evaluation of the change of belief. It simply makes no sense to say that a belief is "truer" than the other in a developing process, because there is no a fixed Archimedean platform in the process that can supply a base to measure the distance between current belief and true belief. To justify the rationality of the incremental change of belief, according to Kuhn, we only have a group of secondary standards, such as accuracy, consistency, breath of applicability, and simplicity. These standards are not fixed but context-dependent, reflecting the restrictions set by time and circumstances. However, these standards really capture the key features of the evolutionary process of human knowledge. Knowledge growth is achieved through an increase of distinct specialties, each of which is dedicated to improve current beliefs about a limited domain in ways to improve accuracy and other secondary standards (Ibid., pp. 18–19).

Kuhn's evolutionary epistemology brings about two important changes in the meaning of incommensurability. First, Kuhn admits that the concept of "scientific revolutions" in *The Structure*, which was defined as episodes in the development of a single science or scientific specialty, is too limited. Scientific revolutions also play "a second, closely related, and equally fundamental role: they are often, perhaps always, associated with an increase in the number of scientific specialties required for the continued acquisition of scientific knowledge" (Kuhn, 1993, p. 336). To evaluate scientific development, we can either compare rival theories by virtue of those secondary criteria, or measure the degree of proliferation achieved in the process of knowledge production. Thus, although incommensurability may continue to create inconsistent evaluation standards between rival communities, giving different weights to particular standards such as accuracy or simplicity, this confusion does not necessarily lead to a total failure of rational comparisons. The evolution of knowledge consists also in the proliferation of specialties, the measurement of which is not only practicable but frequently independent of the theoretical positions of evaluators. The issue of shared standards and the issue of rational evaluation can then be separated, and a rational evaluation of knowledge development is possible even when different evaluation standards are employed.

Moreover, Kuhn's evolutionary epistemology redefines the function of incommensurability. According to the traditional epistemology, the effects of incommensurability are negative: it creates communication difficulties and jeopardizes rational comparisons. But Kuhn now regards incommensurability as a conceptual disparity that separates two specialties. "Once the two specialties have grown apart, that disparity makes it impossible for the practitioners of one to communicate fully with the practitioners of the other. And those communication problems reduce, though they never altogether eliminate, the likelihood that the two will produce fertile offspring" (Kuhn, 1992, p. 20). Thus, incommensurability is positive for the evolution of knowledge: it isolates communities by creating communication barriers and promotes the proliferation of specialties.

With his evolutionary epistemology, Kuhn tries to show that incommensurability does not prevent rational comparisons but promotes the growth of knowledge, and that holist changes of science or human knowledge with incommensurability as a key feature do not result in relativism. But one problem of Kuhn's epistemology is that he builds his arguments mainly upon the analogy to biological evolution. Despite many similarities, scientific development and biological evolution are not the same kind, and have essential differences. For example, scientific theories can adopt elements from each other by interdisciplinary attempts while species usually cannot interbreed, and scientific revolutions frequently have destructive effects (the so-called "Kuhn loss") but not biological evolution. The analogy to biological evolution may give us hints, but not explanatory accounts for scientific development. What we need are rigorous cognitive and epistemological analyses that reveal the causal mechanisms of scientific development. In particular, we need a causal account, not just an analogy, to explain why the progress of science necessarily takes the form of specialization, and why scientific development can be evaluated rationally in terms of the proliferation of specialties.

However, Kuhn's evolutionary epistemology does not provide us with such a causal account. On the one hand, he shows that the proliferation of specialties is inevitable because incommensurability functions as a disparity between different specialties; on the other hand, he argues that incommensurability is inevitable because it promotes the proliferation of specialties. This is a circular argument. According to Kuhn's concept of rationality and those secondary evaluation criteria, the progress of science should take a direction opposite to the proliferation of specialties. For example, such evaluation criteria as consistency, breadth of applicability, and simplicity promote unification rather than specialization. An effective approach to reduce a theory's inconsistency, to expand its application scope, or to simplify its explanatory model is through generalization: a methodology exemplified by the development from Galileo's law of inertia to Newton's mechanics. Thus, if the consistency, the breadth of application, or the simplicity of scientific theories were the only evaluation criteria, scientific progress would not necessarily take the form of specialization, nor could the proliferation of specialties be a rational criterion for evaluating scientific development.

4. THE ROLE OF INSTRUMENTS

One way to overcome Kuhn's difficulties is to examine the role of instruments in the processes of lexical learning and taxonomy establishing, an issue Kuhn has briefly discussed but not fully explored. I will devote the rest of the discussion to this issue, examining how scientific instruments affect the evolution of science through the mediation of lexical taxonomy and the cognitive process of concept learning.

In general, Kuhn appreciates the importance of instruments. He notes that the reality is created by both conceptual and instrumental tools, so that justification in science should aim at the improvement of these tools available for the job in hand (Kuhn, 1992, p. 20; 1991a, p. 7). Kuhn also realizes the connections between the lexical structure of kind terms and instruments, and uses the learning processes of three kind terms in Newtonian mechanics – "force," "weight," and "mass" – to illustrate this point (Kuhn, 1990a, pp. 301–08).

Based upon the understanding of the learning process of kind terms, Kuhn points out that "in the processes through which the new terms are acquired, definition plays a negligible role. Rather than being defined, these terms are introduced by exposure to examples of their use" (Ibid., p. 302). These examples can be introduced by actually exhibiting exemplary situations to which the terms in question can be properly applied, like demonstration experiments in science education, or by verbal descriptions of the exemplary situations. Through these processes, students learn not just meaning of these terms, but how they are applied to a world in which they function.[8]

Differing from most terms used in our daily discourse, those important concepts in science are quantitative. To learn these quantitative concepts, students need to know how to measure them. Due to the limits of our sense organs, we cannot reliably detect positions and movements for other than macroscopic bodies, and cannot accurately notice changes of macroscopic bodies without referring to some kind of measuring units. To make quantitative measurements, we need instruments, which convert effects to be measured to positions or movements of macroscopic bodies and provide measuring units for accurate counting. Therefore, instruments are inevitably involved in the process of learning quantitative concepts.

Thus, the Newtonian concept "force" cannot be learned by referring to its definition – Newton's second law. Nor can it be learned by using an example obtained by direct observation such as a falling stone, which cannot illustrate the quantitative feature of the term. To acquire the Newtonian notion of "force", students need exemplary situations, usually demonstration experiments, in which forces are measured by proper instruments. These instruments can be as simple as a spring balance or some other elastic devices. For example, we can acquire the notion by attaching a spring balance to a heavy body and moving it along an inclined plane.

The significance of instruments in the process of concept acquisition is not simply pedagogical but epistemological, because using different instruments sometimes may affect the results of concept learning. In the seventeenth century, for example, the meaning of "force" might vary if different instruments were used. Using a pan balance, a student in this historical period could only obtain examples of a limited sort of force, the one caused by "weight". Without examples from other sorts of force, such as inertial forces and frictional forces, the student would acquire a notion of "force" quite different from the Newtonian one. With weight-related forces as the only examples, the student could develop the idea that force is the element that overcomes weight, and that a projectile is the typical example of forced motion. This idea could reinforce the highly developed pre-Newtonian intuition that connected force with muscular exertion, and inevitably lead to an Aristotelian concept of force.

Instruments also play an important role in establishing lexical taxonomies. First, instruments practically designate concepts in a lexical taxonomy by sorting their referents under different categories. With a spring balance, for example, we can classify a projectile and a falling stone as forced motion, but categorize inertial motions as force-free. This classification generates a Newtonian taxonomy. With a pan balance in the seventeenth century, however, a student could categorize a projectile as forced motion, but a falling stone as force-free. This classification formed an Aristotelian taxonomy. Thus, as Buchwald recently suggests, instruments sit at the nodes of lexical taxonomies, assigning something to this or to that category (Buchwald, 1992, p. 44).

Moreover, instruments also establish links between nodes in taxonomies. The proper use of a spring balance requires the understanding of theoretical laws, for example, Hooke's law, which states that the force exerted by a stretched spring is proportional to the spring's extension and a constant (the coefficient of elasticity). This constant in turn reflects the material, the dimension, the structure, and the temperature of the spring. Thus, the notion "force" has connections with such concepts as "eleaticity", "material", and "temperature". These connections are obscure without the use of spring balances.

The connections between instruments and taxonomies provide a new dimension for the evaluation of science. If linguistic factors are our only concern, rational comparisons of rival theories, or incompatible taxonomies according to Kuhn's latest version, always involve a vicious circle. On the one hand, taxonomies need to be justified by empirical evidence; on the other hand, the representations of empirical evidence have to be classified and interpreted by the dominant taxonomy. However, differing from linguistic factors, instruments always have lives of their own without necessarily being dominated by paradigm or theory. In addition to the guidance of theoretical knowledge, the development of instruments is also grounded in a material culture, which includes such non-linguistic factors as experimental techniques, procedures, skills, and expertise. In the history of science many instruments were in fact designed and built prior to the formulations of relevant theories, and the advancement of instruments (including the related techniques and skills) continuously shapes the formulation of theory (Chen, 1994, pp. 286–94). The independence of instruments, thus, makes it possible to break the vicious circle.

Recently, Buchwald suggests that taxonomies can be evaluated in terms of their connections with the related instruments. First, a robust taxonomy should not be tied to a particular instrument, but be compatible with many other devices that do the same job but in different ways (Buchwald, 1992, p. 44). Thus, the Newtonian taxonomy is superior to the Aristotelian one, because the former is compatible with not only the spring balance but many other elastic devices, while the latter is tied solely to the pan balance. Second, a robust taxonomy should be able to assimilate novel devices, not only absorbing new concepts created by new devices, but also fabricating new devices (Ibid., p. 60). The Aristotelian taxonomy was inferior to its rival because it failed to absorb such new concepts as "inertial force" and "centripetal force" created by new instruments.

Buchwald's discussion on the robustness of taxonomies indicates that rational comparison during revolutions is possible. The development of science creates not only successive taxonomies that classify the phenomenal world in distinctive ways, but also instruments, procedures, and skills that supply the tools for our interactions with the real world. The achievements of science can then be appreciated both in terms of our ability to account for the phenomenal world correctly and our ability to transform the real world effectively. Due to incommensurability, we may not be able to compare rival taxonomies rationally by examining their linguistic features, but we can evaluate them objectively in terms of their connections with instruments. This new dimension of scientific evaluation is rational: this kind of judgment is not simple a matter of opinion, nor can it be altered by any amount of rhetorical persuasion. Thus, incommensurability without relativism is possible, as long as the instrumental aspect of science has been taken into account.

The connections between instruments and taxonomies can also help us understanding why specialization is a key feature of scientific development, and why rational evaluation of science can be achieved by measuring proliferation of specialties. In fact, if theory is the only element in science, it would be difficult to characterize scientific progress as a process of specialization. As suggests by Kuhn, the criteria for theory evaluation are accuracy, consistency, explanatory power, and simplicity. Most of these criteria, however, promote synthesis and award theories that attempt to provide unified accounts. Evaluations of scientific instruments, however, have distinct criteria. From a cognitive point of view, an instrument is an information transformer – converting input information about the world to output information that can be conceived by our sense organs. So the key criterion for instrument evaluation is the reliability in this information tranformation. A reliable instrument should preserve the relations in inputs and reproduce them with least distortion in outputs. The history of instruments shows that a general approach to improve the reliability of an instrument is to narrow its application scope, that is, to make it special for a limited range of subjects. This is why the history of instruments, say, telescopes, shows a pattern of proliferation: from a single kind of telescope (optical) evolving into a big family, including radio, infrared, ultraviolet, gamma-ray, and x-ray telescopes, each of which covers only a fraction of the light spectrum. The proliferation of instruments provides a material base for the specialization of science. Because of the connections between instruments and taxonomies, the proliferation of instruments may produce different taxonomies, which eventually lead to different scientific communities and disciplines. Thus, in addition to those contextual factors (usually social and/or political) revealed by the social studies of science, specialization in science has its cognitive causes, one of which is the proliferation of instruments.

In conclusion, Kuhn latest notion of incommensurability does not elimentate relativism successfully. Both his theory of kinds and his analogy to bilingualism still imply incomparability under certain circumstances. Although his evolutionary epistemology is promising, it is built mainly upon the analogy between scientific development and biological evolution. However, the significance of Kuhn's latest notion of incommensurability consists not in the conclusion it has made, but in the research direction it suggests. Our brief discussion on the role of instruments in the progress of science shows that incommensurability without relativism is possible. But to fully explore this possibility, we need to adopt an inclusive view of scientific progress, which appreciates not only the importance of scientific theories, but also the values of such non-linguistic elements as instruments, procedures, and skills.

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REFERENCES

Buchwald, J.: 1992, 'Kinds and the Wave Theory of Light', *Studies in History and Philosophy of Science* **23**, 39–74.

Chen, X.: 1994, 'Why Do Scientists Have Disagreements about Experiment?: Incommensurability in the Use of Goal-Derived Categories', *Perspectives on Science* **2**, 275–301.

Chen, X.: 1990, 'Local Incommensurability and Communicability', in A. Fine, M. Forbes, and L. Wessels (eds), *PSA 1990*, Vol. I, Philosophy of Science Association, East Lansing, pp. 67–76.

Hacking, I.: 1993, 'Working in A New World: The Taxonomic Solution', in P. Horwich (ed.), *World Changes*, The MIT Press, Cambridge, pp. 275–310.

Hoyingen-Huene, P.: 1993, *Reconstructing Scientific Revolutions: Thomas S. Kuhn's Philosophy of Science*, The University of Chicago Press, Chicago.

Hoyningen-Huene, P.: 1990, 'Kuhn's Conception of Incommensurability', *Studies in History and Philosophy of Science* **21**, 481–92.

Kuhn, T.: 1993, 'Afterwords', in P. Horwich (ed.), *World Changes*, The MIT Press, Cambridge, pp. 311–341.

Kuhn, T.: 1992, 'The Trouble with the Historical Philosophy of Science, Robet and Maurine Rothschild Distinguished Lecture', An Occasional Publication of the Department of the History of Science, Harvard University.

Kuhn, T.: 1991a, 'The Road Since *Structure*', in A. Fine, M. Forbes, and L. Wessels (eds), *PSA 1990*, Vol. II, Philosophy of Science Association, East Lansing, pp. 3–13.

Kuhn, T.: 1991b, 'The Natural and the Human Sciences', in D. R. Hiley, J. E. Bohman, and R. Shusterman (eds), *The Interpretive Turn*, Cornell University Press, Itheca.

Kuhn, T.: 1990a, 'Dubbing and Redubbing: The Vulnerability of Rigid Designation', in C. Savage (ed.), *Scientific Theory*, University of Minnesota Press, Minneapolis, pp. 298–301.

Kuhn, T.: 1990b, 'An Historian's Theory of Meaning', Talk to Cognitive Science Colloquium, UCLA (unpublished manuscript).

Kuhn, T.: 1989a, 'Possible Worlds in History of Science', in S. Allen (ed.), *Possible Worlds in Humanities, Arts and Sciences*, Walter de Gruyter, New York, pp. 9–32.

Kuhn, T.: 1989b, 'Response to Commentators', in S. Allen (ed.), *Possible Worlds in Humanities, Arts and Sciences*, Walter de Gruyter, New York, pp. 49–51.

Kuhn, T.: 1983, 'Commensurability, Comparability, and Communicability', in P. Asquith and T. Nickles (eds), *PSA 1982*, Vol. II, Philosophy of Science Association, East Lansing, pp. 669–688.
Kuhn, T.: 1981, 'What Are Scientific Revolutions?' Occasional Paper #18, Center for Cognitive Science, The MIT Press, Cambridge. Reprinted in L. Krüger, L. Daston, and M. Heidelberger (eds), *The Probabilistic Revolution*, Vol. I, The MIT Press, Cambridge, pp. 7–22.
Kuhn, T.: 1977, *The Essential Tension*, The University of Chicago Press, Chicago.
Kuhn, T.: 1970, *The Structure of Scientific Revolutions*, The University of Chicago Press, Chicago.
Sankey, H.: 1993, 'Kuhn's Changing Concept of Incommensurability', *British Journal for the Philosophy of Science* **44**, 759–774.
Sankey, H.: 1992, 'Incommensurability, Translation and Understanding', *The Philosophical Quarterly* **41**, 414–426.

NOTES

[1] Hoyningen-Huene recently has provided a reliable account of the development of Kuhn's incommensurability thesis from the 1970s to the early 1980s, see Hoyningen-Huene (1993, pp. 206–22; 1990). For another summary of the evolution of Kuhn's thesis up to the early 1980s, see Sankey (1993).
[2] Kuhn's kind-concept goes beyond the one defined by the theory of natural kinds. He also disagrees with Hacking, who suggests Kuhn to adopt a notion of "scientific kinds" (Hacking 1993, p. 290). Kuhn prefers a more general concept of kind, which covers every individual that can be reidentified by cognitive mechanisms; see Kuhn (1993, p. 315, and 1990b, pp. 11–14).
[3] Kuhn gives detailed analyses of how "mass" can be defined through its connections with other kind terms; see Kuhn (1990a, pp. 301–308), and (1989a, pp. 14–23).
[4] For a detailed discussion of Kuhn's concept of translation in the 1970's and the early 1980s, see Hoyningen-Huene (1993, pp. 256–58).
[5] For more discussions on the differences between understanding and comparison, see Sankey (1991).
[6] Kuhn lately admits that there are essential differences between the learning processes in science and in the history of science, and that the parallel between scientists and historians may be misleading. See Kuhn (1993, p. 324, and 1992, pp. 22–24).
[7] Based upon this understanding, Kuhn notes that the metaphor of gestalt switch is not only inappropriate but damaging in describing the development of science; Kuhn (1989b, 50).
[8] Recent studies in cognitive psychology support Kuhn's analysis. For more on the relations between the psychological theory of categorization and Kuhn's incommensurability thesis, see Chen (1990, 1994).

Department of Philosophy
California Lutheran University, 60 West Olsen Road,
Thousand Oaks, CA 91360–2787
USA