Chapter 5
Interests in Conceptual Changes: A Frame Analysis

Xiang Chen

Abstract In this article, I analyze how interests affect the results of scientific change through concept representation and categorization. I first review two models offered by cognitive psychology, which use frames as the representational structure to account for how interests actually affect concept representation and categorization. I then use a historical case from nineteenth-century optics to illustrate how the interests of historical figures influenced their concept representations, then their classifications and finally the results of their theory appraisal. I conclude that the impact of interests on science is constrained by the states of the world and interests alone can never decide the results of scientific change.

Keywords Conceptual changes • Scientific changes • Frame analysis

5.1 Introduction

As a typical problem-solving activity, scientific research is interest-driven, beginning with a selection of a goal and then an assessment to see what must be changed to achieve the goal (Newell and Simon 1972). Thus, interests of individual scientists and scientific communities affect what scientific research ought to achieve and how science should evolve.

Among scholars of science studies, there are two assessments to the roles of interests in the development of science. Sociologists of science in general highly value the importance of interests. They believe that interests of a scientific community are fully responsible for the results of scientific change. Since all

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interests are socially structured, ultimately social interests, rather than the state of the empirical world, determine the development of science (Barnes and MacKenzie 1979).

Philosophers of science, however, are much less enthusiastic to the discussion of interests. They trend to downplay the roles of interests in science, because they are afraid that acknowledging the impact of interests on scientific development would eliminate the role of the empirical world in knowledge production and ultimately deny science as a rational enterprise. When philosophers of science discuss the roles of interests, they carefully define the type of interest that can legitimately play a role in the development of science. Personal and social interests are off the list. They only accept a small number of epistemic interests, such as increasing empirical knowledge (Hempel 1979), providing explanation (Popper 1975), and reaching approximation to the truth (Newton-Smith 1981).

Despite their differences, both the sociological and the philosophical approaches toward interests are built on an assumption that the impact of interests on science is subjective, reflecting solely the desires of people and not constrained by the state of the empirical world. This assumption, however, overestimates the role of interests in scientific change. In this article, I analyze how interests affect the results of scientific change through concept representation and categorization. In the following sections, I first review two models offered by cognitive psychology, which use frames as the representational structure to account for how interests affect concept representation and categorization. I then use a historical case from nineteenth-century optics further to illustrate how differences in concept representations resulted in different taxonomies and eventually different judgments in theory appraisal. I conclude that the roles of interests in concept representation and categorization are far less decisive than what many people believe, and that the impact of interests is not entirely subjective because it is always constrained by the state of the empirical world.

5.2 Interests and Attribute Weights

One way to learn the precise roles of interests in concept representation is to analyze the process of concept combination. Our understanding of the meaning of a concept may not be the same due to different purposes or interests. For example, to those who are watching their weights, their interest to lose weights would modify their concept of food and the related taxonomy of foods – foods are either "appropriate on a diet" or "inappropriate on a diet." These interest-modified concepts are roughly identical to such adjective-noun conjunctions as 'low-calorie foods' and 'high-calorie foods.' Hence, it is reasonable to assume that the way that interests modify a concept is similar to the process of forming adjective-noun conjunctions, where an adjective modifies the meaning of a noun to form a new composite concept.

Smith and his cooperators offered a detailed account, a selective modification model, to explain how people combine adjectives and nouns to form composite concepts (Smith et al. 1988). To begin with, this selective modification model requires a frame representation of concepts. A frame is a set of multi-valued attributes integrated by structural relations. Thought highlighting the hierarchical relations between attributes and values, the structural connections between attributes, the constraints between value sets, and attribute weighting, a frame representation can reveal the complexity of intraconceptual relations within a concept.

The frame for the concept of *apple*, for example, has a list of three attributes: *color*, *shape*, and *texture*, which are properties shared by all exemplars of *apple*. Associated with each attribute is a set of values; for example, *red*, *green* and *brown* are the values associated with the attribute *color*, *round*, *square* and *cylinder* with *shape*, and *smooth*, *rough* and *bumpy* with *texture*. Features in the value list are activated selectively to represent the prototype of a specific subordinate concept. For example, a typical apple is an object whose value for *color* is *red, shape* is *round*, and *texture* is *smooth*.

The frame representation uses attribute weighting to indicate the salience of each attribute. Attribute weighting indicates how useful each attribute is in discriminating instances of the concept from instances of contrasting concepts. Consider the frame for *apple*. Since *color* is the most useful attribute in discriminating apples from non-apples, it is given the highest score, and *shape* and *texture* are given lower scores.

Smith also includes indication of the salience of each relevant value. When people are asked to verify whether a property is true of a particular concept, they usually respond faster and more reliable to properties that belong to the prototypes. Because the prototype of *apple* is red, people are faster and more accurate at deciding whether "apples are red" than "apples are green." Thus, *red* is a most salient value and is assigned the highest score, while *green* and *brown* are lower.

The selective modification model assumes that adjective and noun concepts play different and asymmetrical roles in the process of concept combination. Specifically, nouns offer the basic frames to be operated on and adjectives function as modifiers by selecting and changing the corresponding attribute and values in the noun concepts. Consider a process through which *red* and *apple* are combined to form an adjective-noun conjunction – *red apple* (Fig. 5.1). To begin with, the adjective *red* selects the corresponding attribute in the noun, which is *color*. Then, for the selected attribute, there is an increase in the salience of the value given by the adjective. The score of *red* in *color* increases by getting all the scores from other values under the same attribute. The salience of the corresponding value increases because the change from *apple* to *red apple* signals a change in the prototype –*red* is more representative to *red apple* than to *apple*. Furthermore, there is also an increase in the salience of such selected attribute as *color*. This is because there is a change in the perceived contrast class of the concept. As *apple* is changed to *red apple*, the contrast class is also changed from *orange* to *green apple*. In this way, *color* becomes the only discriminating attribute for categorization.

The selective modification model illustrates a possible mechanism to explain how interests affect concept representation. When people try to comprehend a subject,

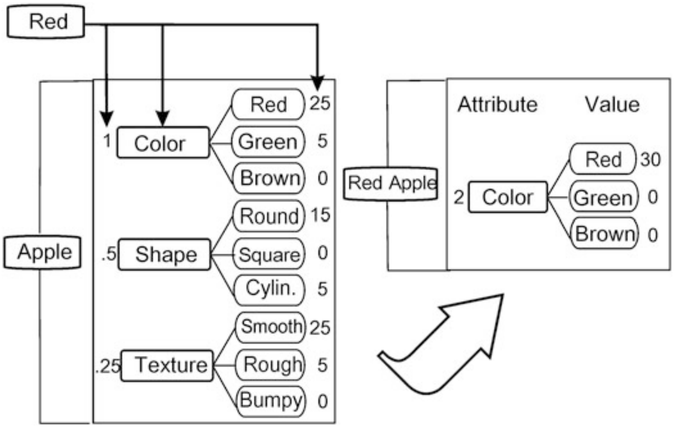

Fig. 5.1 The process of concept combination (Reproduced from Smith et al. (1988))

they always focus on certain aspects of it according to their interests. In the process of conceptualization, they tend to give extra weights to attributes corresponding to their interests, and form an interest-modified concept. Such an interest-modified concept can subsequently change the classification of the field. Many similarity-based models of categorization allow for selective weighting of features, which are equivalent to stretching or shrinking some dimensions of the similarity space. In the process of categorization, those features with extra weights usually cause attention and become classification standards.

5.3 Interests and Optimal Values

We often construct concepts while making plans to achieve goals. Many of these constructed concepts are ad hoc in the sense that they are derived in an offhanded manner to achieve current interests. This process of making concepts in the fly is top-down and creative. Experience from exemplar learning appears irrelevant for ad hoc concepts because little experience with exemplars is necessary. Unlike common taxonomic concepts in which prototypes are represented by central tendency, prototypes of ad hoc concepts are represented by ideals that arise from reasoning with respect to interests (Barsalou 1983). Frequently, these ideals do not really exist; for example, the ideal for *foods to eat on a diet* is *zero calories*.

Barsalou performed an exploratory study to examine how people construct ad hoc concepts to make plans (Barsalou 1991). In the study, Barsalou asked the subjects to describe the processes of planning interest-driven activities, such as taking a trip, making a purchase, repairing a tool, and attending a social gathering. By analyzing the subjects' protocols, Barsalou identified a general procedure for constructing ad hoc concepts to fulfill interests.

Barsalou's analysis also requires a frame representation of concepts. To plan a familiar type of interest-driven activities such as a vacation, people usually first retrieve from their memory a general frame for it. Barsalou found that the subjects' representation of *vacation* contains six attributes: *actors*, *departure time*, *location*, *activity*, *cost*, and *thing to take as gifts*. Among them, some can be further analyzed to form a cluster of attributes at a secondary level. For example, *location* includes a group of specific attributes such as *hemisphere*, *terrain*, *climate*, *scenery* and *popularity*.

After a general frame is available, people begin to instantiate its attributes, that is, to adopt specific values for the attributes. Instantiation is the primary activity of planning, and the results of instantiation, that is, which value is selected for a particular attribute, are determined by the interests that people set up for the planned activity. Specifically, interests set up ideals in the process of instantiation. For example, if to save money is the interest, then the ideal for *cost* would be *zero*, and if to reward myself after receiving the bonus is the interest, then the ideal for *departure time* would be *immediate*. These ideals are specific characteristics that exemplars of *vocation* should have in order to achieve the interests.

Once an ideal is established, it guides the selection of values for the related attribute. They should contain an optimal value that is close or identical to the ideal, and several others that are at various distances from the ideal; for example, when *zero cost* is the ideal, the value set of *cost* should include a lowest possible number as the most desirable value and several others at various distances from *zero cost*. Sometimes, when people highly value an interest, they could further emphasize the optimal value, and regard others from the same value set as equally undesirable. As the result, the value set could have a dichotomous structure, with only a desirable and an undesirable value; for example, when the interest to reward myself after receiving the bonus is very important, the optimal value of *departure time* could be *within days*, and all other values of longer time frames could be simply grouped together under *later*. This is a process of optimization, in which values approximate to ideals set up by the interests are selected.

Figure 5.2 illustrates the process of optimization in constructing *vacation*. First, the interests of privacy and aesthetic enjoyment establish the ideals for *popularity* and *scenery*, and select *minimally popular* and *maximally beautiful* as the optimal values. Similarly, the interests to receive immediate reward and to learn a snow sport select *July* and *skiing* as the most desirable values for *departure time* and *activity*.

After we select the optimal values for some attributes through optimization, these optimal values would impose constraints on the selections of values for other attributes, because concepts must be coherent with compatible value selections. For example, if one has decided that the desirable value of *activity* is *snow skiing*, then one cannot select just any location to instantiate *vocation*. No meaningful concepts can be formed on incompatible values between *activity* and *location*. In this way, the optimal values for *activity* and *departure time* impose constraints on the selections of values for *hemisphere*, *terrain* and *climate*.

Barsalou's analysis illustrates another mechanism to explain how interests affect concept representation. People construct ad hoc concepts to achieve goals defined

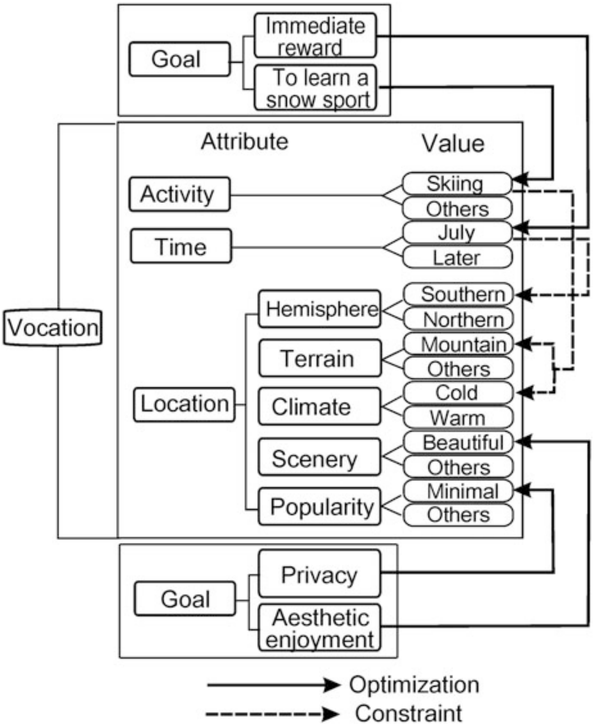

Fig. 5.2 Reconstructing vocation through optimization (Reproduced from Barsalou (1991))

by interests. In this process, interests set up ideas and instantiate a concept through optimizing values and imposing constraints. Constructing concepts in this way would also change the classification of the field. Because we construct ad hoc concepts to reflect interests, instances of ad hoc concepts do not appear to share correlated properties. For example, instances of *things to take from one's home during a fire* may include very different objects such as children, dogs, stereos and blankets (Barsalou 1983). Taxonomies of ad hoc concepts frequently violate the correlational structure of the real world to such a degree that they are no longer accountable by changing the weights of attributes.

The process of optimization also predicts that taxonomies of ad hoc concepts could have a unique structure. Consider the number of possible subordinate concepts under *vacation* without the impact of interests. With six attributes, each having two values or more, there are at least 64 possible property combinations (2 × 2 × 2 × 2 × 2 × 2), and therefore at least 64 possible subordinate concepts. However, the process of optimization significantly reduces the number of possible subordinate concepts. First, optimization may generate dichotomous values through highlighting the most desirable ones and treating all others as undesirable. Furthermore, optimal values can impose constraints to the selections of values for other attributes. Consequently, interests generate many conceptual gaps in the taxonomic structure; that is, many subcategories of an ad hoc concept do not exist. In some extreme cases where all attributes are either optimized or constrained so that they have only a preferred value, the number of the subcategories could be reduced to one.

5.4 Interests and Theory Appraisal

The optical revolution – the conceptual change from the particle to the wave theory of light in the early nineteenth century – was a good example to illustrate how scientists' interests affected the results of a scientific revolution. Historical studies have indicated that changes of classification systems preconditioned the optical revolution: only after taxonomic changes did the superiority of the wave theory became compelling (Chen 1995). Through this historical episode, we can learn how the communal interests of historical figures first influenced their concepts of *light*, then their classifications of optical phenomena, and finally their judgments of the two rival theories.

On the eve of the optical revolution, the dominant taxonomy was a system built upon the particle concept of *light*. According to the particle tradition, light consists of a sequence of rapidly moving particles susceptible to attractive and repulsive forces defined by the laws of mechanics. Thus the particle concept of *light* contained four attributes: *force* (*attractive* or *repulsive*), *velocity* (*changed* or *unchanged*), *size* (*small* or *large*) and *side* (*orderly* or *random*). Among them, *force* was given the highest weight, because, from the Newtonian point of view, mechanical forces are the causes of all optical phenomena.

Such a concept of *light* defined the taxonomy, which divided optical phenomena into eight categories: *reflection*, *refraction*, *dispersion*, *diffraction*, *Newton's rings*, *double refraction*, *polarization*, and *absorption* (Brewster 1831). This taxonomy highlighted the defects of the wave theory. Because the wave theory could not account for dispersion and absorption but its rival could, there was no reason to replace the particle theory with the wave theory (Brewster 1832).

In 1827, John Herschel introduced a new concept of *light*. Herschel began his optical research as a believer of the particle theory, but he was convinced by the successes of Fresnel's wave theory in the early 1820s. Around 1824, Herschel wrote a comprehensive review essay to introduce Fresnel's wave account to the Britain audience (Herschel 1827). The main purpose of this essay was to present the conceptual framework of Fresnel's account and eventually to revitalize the wave tradition in Britain.

In the early nineteenth century, most supporters of the wave tradition believed that light consists of disturbances in a medium called ether. To describe the motion of a periodic disturbance, they needed four parameters according to the wave equation: *velocity*, *amplitude*, *wavelength*, and *phase difference*. All optical phenomena were supposed to be explained in terms of these four parameters, and no reference to *force* was necessary.

These four wave parameters became the attributes in Herschel's concept of *light*. Herschel gave *wavelength* the highest weight, because it was the only attribute that could represent the typical characters of waves. Both the particle and the wave theories defined *velocity* in the same way, and there were significant similarities between *amplitude* in the wave framework and *size* in the particle framework because both defined intensity of light. In theory, *phase difference* was a unique wave attribute, but Herschel did not understand this notion correctly. He failed to complete the conceptual change from *side* to *phase difference* and continued to adopt the former to represent polarization (Chen 2003). With the interest to revitalize the wave theory in Britain, it was logical for Herschel to emphasize *wavelength* as the key character of light.

Without *force* as a classification standard, it became unnecessary to separate *reflection* from *refraction* – they were just changes of direction. *Dispersion* and *absorption* should belong to the same category, called *chromatics* by Herschel, because both were interactions between light and matters. *Double refraction* was no longer an independent category but under *polarized light*, because what kind of force involved was no longer considered. At the same time, since *wavelength* was assigned the highest weight, phenomena associated with this attribute should be separated and highlighted. In the context of the early nineteenth century, they were the phenomena of interference, diffraction and the Newton's rings. Thus, Herschel formed a new category *interference* to cover these phenomena. At a result, Herschel's concept of *light* generated a taxonomy with four subordinate categories: *direction of light*, *chromatics*, *interference*, and *polarized light*.

Theory appraisal under this taxonomy was in favor of the wave theory. The wave theory was superior because it could successfully explain three major categories except *chromatics*, while its rival failed in two major categories (*interference* and *polarization*). However, Herschel's taxonomy continued to highlight the wave theory's failure in dispersion. When Herschel evaluated the two rival theories, he developed a preference for the wave theory, but he was reluctant to embrace it completely. The explanatory success of the particle theory in dispersion and absorption, which represented an important category, led him to believe that the particle theory was still valuable. In a rather long period after he established his preference for the wave theory, Herschel did not believe that the particle theory should be totally abandoned.

In his report presented to the British Association in 1834, Lloyd introduced another concept of *light* (Lloyd 1834). At the beginning of the 1830s, wave theorists in Britain were under pressure. On the one hand, Brewster used the particle taxonomy as the framework to highlight the difficulties of the wave theory. On the other hand, Herschel continued to believe that the particle theory should not be abandoned. To complete the revolutionary change in optics, wave theorists in Britain had a strong interest in demonstrating the necessity of replacing the particle with the wave theory. Such a general interest was set in the unique context where polarization had become the most exciting research subject in optics. Between the 1810s and the 1820s, a large number of novel phenomena related to polarization was found. The wave theory in general was successful in accounting for polarization, while the particle theory remained cumbersome in this field. Thus, Lloyd adopted a specific tactics to achieve the general interests of the wave camp, that is, he wanted to highlight the wave theory's successes in polarization.

Lloyd's concept of *light* originated from Fresnel's account of polarization. According to Fresnel, the differences between polarized and unpolarized light consisted in the phase difference and the amplitude ratio of the two perpendicular components of the light beam: the two perpendicular components of polarized light always have a fixed phase difference and a fixed amplitude ratio. Thus, polarization could be represented by two attributes: *amplitude ratio* and *phase difference*. To demonstrate the superiority of the wave theory in polarization, Lloyd built an ad hoc concept through a process of optimization, in which the interest of highlighting the wave theory's successes in polarization sets up the ideal of *light*. Given the specific interest, polarized light became the ideal exemplar of *light* in order to demonstrate the superiority of the wave theory. This ideal further determined the value sets of the attributes *amplitude ratio* and *phase difference*. Instead of taking continuous values, they have a dichotomous structure. For *phase difference*, *stable phase difference* is desirable and *unstable phase difference* is undesirable; for *amplitude ratio*, *stable ratio* is desirable and *unstable ratio* undesirable.

Lloyd's concept of *light* generated a taxonomy with a unique dichotomous structure. Lloyd's taxonomy first classified all optical phenomena solely in terms of their states of polarization. *Polarized light* and *unpolarized light* were the only two major categories, and many categories treated as major in other systems, such as *reflection*, *dispersion*, and *diffraction*, now became subcategories, or even sub-subcategories. This taxonomy violated the correlational relations between optical phenomena, with categories cut across the correlational structure of the environment. Instances of *polarized light*, which included propagation and color, did not appear to share correlated properties; instead, they shared many correlated properties with entities in the other category.

Under this new taxonomy, Lloyd was able to make persuasive arguments that the community should abandon the particle theory and adopt the wave theory immediately. By listing the wave theory's successes in both major and secondary categories, Lloyd showed its superiority over the particle theory. Under his system, the wave theory was able to have a total control of one of the two major categories – *polarized light*, in which the particle theory experienced tremendous difficulties. In the other major category – *unpolarized light*, the wave theory had demonstrated its superiority in such secondary categories as *propagation of light and interference*, *diffraction*, and *colors of thin plates*, while the particle theory had no currency at all. At the same time, Lloyd was able to deal with the difficulties of the wave theory. Lloyd admitted that dispersion was the most formidable obstacle to the theory. However, under his dichotomous taxonomy, the troublesome cases of dispersion and absorption became third-level categories. Here, the tacit argument was that dispersion and absorption were no longer relevant to theory appraisal.

5.5 Conclusion

Interests impose genuine and profound impact in concept representation and categorization. Cognitive psychology has provided explanatory frameworks for us to understand how interests actually affect the processes of concept representation and categorization. According to the selective modification model, for example, interests affect the result of concept representation by changing the salience of related attributes and values, as exemplified by the concept of *light* adopted by Herschel on the eve of the optical revolution. According to the studies of ad hoc concepts, interests alter the result of concept representation through a process of optimization and constraint, as demonstrated by the concept of *light* that Lloyd adopted during the optical revolution. With different concept representations, we construct different taxonomies, since classification standards come from superordinate concepts. With different classifications, we make different theory appraisals. The historical example from nineteenth-century optics substantiates the cognitive accounts of the mechanisms that underlie the interest-driven process of classification and verify the role of interests in scientific change in general.

However, the role of interests in the process of concept representation is far less subjective than what had been described by many sociologists and philosophers of science. In representation, people cannot freely modify or construct concepts solely according to their interests. They do not have the freedom to frame a concept out of subjective contemplation, nor can they make purely subjective and arbitrary selections among various possibilities. How interests affect representation is not a purely subjective process, because it is still constrained by the states of the world.

In the process described by the selective modification model, for example, interests can alter the representation of a concept by changing the salience of certain attributes and the weights of certain values under the selected attributes. However, people cannot arbitrarily select and highlight certain attributes or values solely according to their interests. A certain interest can select and modify only those relevant attributes and values, and whether an attribute or a value is relevant is defined by the states of the world. For example, when Herschel modified the concept of *light* according to his interests of introducing the wave theory to the British audience, he had no choice but selecting and highlighting the attribute *wavelength* because this attribute was the only one that reflected the unique features of the wave theory. Furthermore, people cannot increase the salience of attributes and values arbitrarily. They can only increase the scores of attributes and values to degrees consistent with the states of the world. For example, no matter how strong the interest to lose weight is, one can only increase the salience of *low calorie* by combining all the scores from other values under the attribute of *calorie*. Impact of interests on representation is always limited to directions and ranges permissible by the states of the world.

In the process of constructing ad hoc concepts, the impact of interests is extensive, spreading to every attribute through constraints, and interests can select values that do not even exist through optimization. However, the role of interests is still not arbitrary. Interests can establish ideals through optimization, but only those ideals consistent with the environment are accepted. For example, an interest to learn a snow sport in planning a vacation would not establish an ideal of *snow diving*, which is something physically impossible. Similarly, when an interest imposes constraints, it is effective only when causal connections indeed exist between related attributes. The interest to ski in July can restrict the value of *hemisphere* but not that of *popularity*, because there are causal connections between activities in a certain season and geographical locations defined by the physical structure of the earth, but there are no possible causal links between the former and the density of population. Most importantly, though interests have comprehensive influences on concept representation, they do not create concepts. The impact of interests is limited to filling in the details for a frame that has been retrieved from memory and accepted as the starting point of constructing an ad hoc concept. When Lloyd constructed a new concept of *light* according to the interest of highlighting the wave theory's successes in polarization, he used the existing frame for *light* from the wave tradition as the starting point. Through optimizing values and imposing constraints, Lloyd changed the values of two attributes. But the processes of optimization and constraint did not alter the existing list of attributes and the structural relations among them. Experiences based on similarity observations continued to function as a foundation for Lloyd to create a new concept.

The limited and non-arbitrary role of interests in concept representation is consistent with findings regarding perceptually based information in categorization. Cognitive studies have found that observations at the perceptual level frequently interfere with categorization, despite theories having defined them as irrelevant. A classical example is the so-called Stroop interference. When subjects were asked to name the color of a word printed with colored ink, the speed and accuracy of their judgments were affected if the word was the name of a conflicting color, such as the word "red" printed with blue ink – the observations of words interfered with the judgments of colors despite clear instructions (Stroop 1935). Similar evidence also comes from studies of the impact of prior episodes in categorization, where subjects were found to be influenced by observations learned in the training phase, even though they were told specifically to ignore these previous observations and to follow a set of different rules (Allen and Brooks 1991). Thus, even within the limited domain where they are effective, interests are not dominant. Observations at the perceptual level and information about the states of the world continue to influence the processes of representation and categorization, regardless of whether they are consistent with the expectations of interests.

Thus, interests alone never decide the results and directions of scientific change. The concern that acknowledging the role of interests in scientific change would deny science as a rational enterprise overestimates the impact of interests. Such an overestimation originates from a faulty representational method that threats concepts as atomic entities, examining merely the connections between concepts and the relationships between concepts and their referents. Without considering the internal structure of concepts, how exactly interests affect concept representation remains unclear. By using the frame model to illustrate the internal structure of concepts, we learn in which ways interests affect scientific change. We learn that the impact of interests is localized, limited to specific components of a concept, and that the internal structure of a concept as a whole continues to reflect the state of the world. The impact of interests on science is conditioned and constrained by the states of the world. Thus, acknowledging the role of interests in scientific change does not imply that science is no longer a rational enterprise.

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References

Allen, Scott, and Lee Brooks. 1991. Specializing the operation of an explicit rule. *Journal of Experimental Psychology. General* 120: 3–19.

Barnes, Barry, and Donald MacKenzie. 1979. On the role of interests in scientific change. In *On the margins of science: The social construction of rejected knowledge*, ed. Roy Wallis, 49–66. Keele: University of Keele.

Barsalou, Lawrence. 1983. Ad hoc categories. *Memory and Cognition* 11: 211–227.

Barsalou, Lawrence. 1991. Deriving categories to achieve goals. In *The psychology of learning and motivation*, vol. 27, ed. Gordon Bower, 1–64. New York: Academic.

Brewster, David. 1831. *A treatise on optics*. London: Longman.

Brewster, David. 1832. Report on the recent progress of optics. *Annual Reports of the British Association* 2: 308–322.

Chen, Xiang. 1995. Taxonomic changes and the particle-wave debate in early nineteenth-century Britain. *Studies in History and Philosophy of Science* 26: 251–271.

Chen, Xiang. 2003. Why did Herschel fail to understand polarization? The differences between object and event concepts. *Studies in History and Philosophy of Science* 34: 491–513.

Hempel, Carl. 1979. Scientific rationality: Analytic vs. pragmatic perspectives. In *Rationality today*, ed. Theodore Geraets, 46–58. Ottawa: University of Ottawa Press.

Herschel, John. 1827. Light. In *Encyclopaedia metropolitana*, ed. Peter Barlow, 341–582. London: Griffin.

Lloyd, Humphrey. 1834. Report on the progress and present state of physical optics. *Annual Reports of the British Association* 4: 295–413.

Newell, Allen, and Herbert Simon. 1972. *Human problem solving*. Englewood Cliffs: Prentice-Hall.

Newton-Smith, William. 1981. *The rationality of science*. London: Routledge.

Popper, Karl. 1975. The rationality of scientific revolutions. In *Problems of scientific revolution*, ed. Rom Harré, 72–101. Oxford: Oxford University Press.

Smith, Edward, Daniel Osherson, Lance Rips, and Margaret Keane. 1988. Combining prototypes: A selective modification model. *Cognitive Sciences* 12: 485–527.

Stroop, John. 1935. Studies on interference in serial verbal reactions. *Journal of Experimental Psychology* 18: 643–662.