# An Adaptive Model of Category Construction with Similarity Defined by Internally Generated Constraints

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## ABSTRACT

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It is understood that similarity must be appropriately constrained if it is to be a useful construct in a theory of concept formation (Medin, Goldstone & Gentner, 1993). To that end, a framework of knowledge development is proposed to provide an account for cyclic cognitive progression. In this account, categorization always takes place at a particular cognitive level, where data (i.e. observed phenomena in the experience field), the pre-existing knowledge and goal are interrelated, and where appropriate constraints for similarity judgment in categorization are derived internally using the pre-existing knowledge and goal. An adaptive model is developed to specify the mechanisms of categorization. It has three components: an expanded experience base; a preference-rule based interaction, involving an innate standard of similarity, the pre-existing knowledge and goal to generate internal constraints; and a negotiation process in which the cognitive system with a perspective formed within the constraints adapts to the data but seeks maximum consistency with the perspective in adapting, thereby producing family resemblance (FR) categories. Two experiments were conducted to test this adaptive model by using sorting tasks. The goal of the experiments is to see if the adaptive model can account for the family resemblance structure widely observed in natural categories. The adaptive model was compared with the existing similarity-based model in the first experiment and with the two-stage model (Ahn & Medin, 1993) in the second. The results show that the new adaptive model can account for FR categories better than either the similarity-based model or the two-stage model. This supports the view that internal constraints derived from pre-existing knowledge and goals do play an important role in categorization. Implications of this knowledge framework and adaptive model for effecting conceptual change and for designing instruction for concept teaching are discussed.

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To my wife Chenfeng and my daughter Wenya.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Area of Study: Formation of Institutionalized Concepts

Why do we need concepts and categories? Generally speaking, concepts and categories serve as building blocks for human thought. Thinking has to operate on concepts and categories, for "... absolute uniqueness imposes the prohibitive cost of ignorance." (Medin 1989, p. 1469) The cost of ignorance is in terms of inability to make inference in thinking because inference is based on categories. For example, how do we know that a thing will dissolve in water though it is destined never to get into water? We know that by making inference and using the category of soluble things. That is, we know a thing is soluble though it never gets into water because it is of the same kind as the things that actually dissolved or will dissolve in water (Quine 1977, p.168).

Coherent thinking not only operates on concepts and categories, but also observes a set of conditions. Take "The man slept soundly" and "Green ideas slept furiously". The first sentence is a coherent cognitive operation while the second is not, because "man" as a biological being has a sleeping phase in his life cycle while "idea" does not. According to Keil (1989), the second sentence is a category mistake, for it mixes up two ontologically different kinds. There are other kinds of restrictions. For instance, the predicate "pregnant" cannot be sensibly applied to the term "man" because "pregnant" presupposes the feature of FEMALE in the term whereas "man" has the feature of MALE. Therefore, a contradiction would result if "man" is predicated with "pregnant". Later on, we will see a restriction in terms of cognitive levels. If concepts at a lower cognitive level are applied in performing cognitive tasks at a higher cognitive level, a category mistake or contradiction might result, but mostly these concepts are simply not adequate for the tasks of that level.

Since concepts and categories are fundamental constructs in thinking, concepts and concept formation have been an area of intensive research in cognitive science. But what is a concept and what is a category? Historically, there are more definitions that can be applied to both a concept and a category than there are those formulated to distinguish between the two terms. For instance, in the literature of cognitive psychology, the terms "concept" and "category" are frequently used next to each other with the same set of assertions applied to both. An example is found in Medin (1989, p. 1470): "The classical view of concepts is organized around this notion. The classical view assumes that mental representations of categories consist of some lists of features or properties." Donald Homa (1984) gives the following definition to a category: "In the simplest and most inclusive case, a category may be defined by the assignment of a common name to an arbitrary collection of stimuli." (p.59) This definition takes a very superficial position by capturing only the fact that a category groups together a collection of distinct entities. Nothing is said about the structure of a category and no attempt is made to distinguish a concept from a category. Holland, Holyoak, Nisbett and Thagard (1987) define both concepts and categories as rule clusters. (p.17) Their definition of a concept is: "A concept is a data structure that explicitly clusters rules concerning a particular category." (p. 94) They offer the following as the definition of categories: "This conclusion follows from our assumption that categories are best defined as clusters of interrelated rules and that rules are in turn the product of goal-directed inductive mechanisms." (p.179) In Holland et al. a concept is thus seen as an organizing principle which guides clustering of rules while a category is seen as a product of this clustering. A concept and a category may have the same structure but differ in focus. Medin (1989), for instance, explicitly takes this approach: "Roughly, a concept is an idea that includes all that is characteristically associated with it. A category is a partitioning or class to which some assertion or set of assertions might apply." (p.1469) Here the distinct natures of concept and category are still not fully distinguishable, for an idea that includes all that is characteristically associated with it is a class to which some assertion or set of assertions might apply. As a matter of fact, because a group of distinct entities are characteristically associated, some assertions can be applied to all of them. However, this lack of clear distinction between a concept and a category does not represent a major problem for this project, since the family resemblance structure, which this project intends to account for, is an observed property of both concepts and categories as defined above.

Like many other areas of scientific research, the study of concepts can be of two types. The first type studies the characteristics or properties of concepts and the second type attempts to account for the production of those characteristics and properties. The distinction between the two is not always clear, because properties always have theoretical implications and indeed many of them are established in theoretical works accounting for concept formation. However, the distinction is a useful one. For instance, in an attempt to theorize about concept formation, one must account for all the properties of concepts generally accepted by the research community, even though one may reject some theories from which these property categories come. This is exactly what this project intends to do. In the literature review in the next section, while various theories of concepts are reviewed, emphasis will be given to the description of the properties of concepts, which this project will account for in an attempt to explain concept formation.

Another distinction should be made between concept formation and concept learning for this project. Concept formation is defined as a process of organizing a set of information/data into new functional mental constructs, i.e. concepts, so that the cognitive system can operate with the concepts in abstract reasoning. Though this is a process of learning in the most fundamental sense of the word, we will call it concept formation in order to distinguish it from another type of learning. Concept learning here refers to the process of acquiring existing concepts through instruction, reading, or other forms of communication. The distinguishing feature in this case is whether the cognitive system in question has to explore and organize the information for the first time. The distinction is useful because, later on in this project, we will discuss implications of the proposed concept formation model to concept learning, where concept acquisition is guided by instruction.

Scientists, researchers, poets and people who work at the forefront of knowledge development are certainly engaged in concept formation activities very frequently. But everyone has to perform concept formation in his/her life. We form our personal views on many issues and we constantly create what Barsalou (1983) calls ad hoc categories in everyday problem solving situations. Categories like "things to take on the trip", "foods to eat while on diet" and "things to take out in case the house is on fire" etc. are created to meet the needs of specific situations. These categories serve a cognitive function of organizing information into distinct entities so that they can be related to other categories in a meaningful way in terms of achieving the goal. Of course, we all learn concepts. Note that even when we create functional ad hoc categories, the component concepts are often learned. In "foods to eat while on diet", "food", "eat" and "diet" are all learned concepts.

Personal concepts are functional for the person who holds them. Ad hoc categories will be conveniently forgotten when the situation in which they were created no longer exists. There is another type of concept, which we can call "institutionalized concepts". These concepts are shared by people in a society or a community (e.g. a culturally stable community or the science community) and are relatively permanent. The basic concepts of this type are lexicalized and constitute our basic cognitive repertoire (Leech, 1981). Concepts such as "food", "people", and "trip" in our everyday life, and "force", "heat", "atom" and "gene" in science, are shared and collectively owned as part of our knowledge of the world. These concepts are so basic to our understanding of the world and our thinking that we often refer to children's learning of them as "vocabulary learning". It becomes an insight when someone says that when children acquire a language, they also acquire the classification systems of the language, while in fact the children are learning to "inherit" the basic understanding of the world, that is, how the world around them is divided and categorized in their culture. It is the formation of these institutionalized concepts that this thesis investigates.

## 1.2 Theories of Concepts and Concept Formation

### 1.2.1 The classical view

The classical view is organized around the idea that examples of a category have fundamental characteristics in common. It defines concepts in terms of sets of features or properties that individually are necessary for category membership and collectively are sufficient to determine category membership (Bruner, Goodnow, & Austin, 1956; Katz & Postal, 1964). The category "triangle" fits this definition well. All triangles have three sides, are closed geometric forms, and have interior angles that sum to 180 degrees. If any of these properties is missing, one does not have a plane triangle.

However, the classical view is not adequate for everyday concepts even at the descriptive level. It makes two assumptions that most natural categories do not fulfil. The first is that concepts have defining features or attributes. This assumption was challenged by Wittgenstein (1953), who showed that lexical concepts like "game" do not have necessary and sufficient defining features. Rather, a family resemblance might be what links the various referents of a word. A family resemblance relationship consists of an open set of items of the form AB, BC, CD... Each item has at least one or more elements in common with one or more other items, but no or few elements in common to all items. Indeed, linguists, philosophers, biologists, and clinical psychologists alike have been unable to supply a core set of features that a concept (in their area of expertise) necessarily must share (Medin, 1989). The second inadequate assumption of the classical view is that all examples of a concept are equally good, since they all possess the requisite defining features. This assumption was challenged by a series of experiments in the mid 1970s (Smith, Shoben, & Rips, 1974; Rosch, 1973; Rosch & Mervis, 1975; Rips, Shoben, & Smith, 1973). The consensus is that concepts have typicality effects. For example, people judge a robin to be a better example of bird than an ostrich and can answer category membership questions more quickly for good examples than for poor examples. Furthermore, the classical view was found incapable of accounting for unclear cases. Should a rug be considered furniture? People disagree with each other concerning the category membership of many objects and even contradict themselves on separate occasions (Barsalou, 1989; McCloskey & Glucksberg, 1978). These and other problems have led to the rejection of the classical view of concepts.

### 1.2.2 The probabilistic view and exemplar view

Along with the rejection of the classical view came the probabilistic view, which holds that categories are "fuzzy" or ill-defined and that categories are organized around a set of properties that are only characteristic or typical of the category members (Rosch, 1975a). Rosch and Mervis (1975) had subjects list properties of exemplars for a variety of concepts such as "bird", "fruit", and "tool". They found that the listed properties for some exemplars occurred frequently in the concept, while others had properties that occurred less frequently and, most importantly, the more frequent an exemplar's properties were, the higher its rating for typicality in that category. Rosch and Mervis defined and developed a measure called "family resemblance", which increases with the within-category similarity and decreases with the between-category similarity. Furthermore, family resemblance is highly correlated with the speed with which an exemplar can be categorized, and with other typicality effects. Their experiments show that concepts do not all need to have common defining features to keep members in the category. Rather, the members or the subsets of a concept can be held together in a family resemblance relationship. More specifically, their findings can be grouped in the following way:

- Of the natural concepts (for both superordinate and basic-level concepts), the more an item has attributes in common with other members of the category, the more it will be considered a good and typical member of the category and also the fewer attributes it shares with categories other than the category in question (pp.582 - 586).

- Of the artificial concepts, "items that have greater degree of family resemblance with the members of their own set are learned more rapidly, identified more rapidly even after practice and judged as more prototypical members of the category than are items with a lesser degree of family resemblance" (pp. 596-597). Conversely, "items are considered more prototypical of a category to the extent that they do not overlap with contrasting categories" (p.596).

The probabilistic view deals with problems that undermine the classical view. The probabilistic view holds that categories are organized according to the family resemblance principle. That is, a category has a prototype or an ideal which possesses all the characteristic features of the category. Members of the category do not have to share all the features, but they have to share a sufficient number of features and share them to a sufficient degree. By "sufficient", it is meant that a member shares more features with other members of the same category than with non-members across categories. From the category's point of view, it maintains its systemic integrity and existence only when its features are shared more among its members within the category than between the categories. In other words, it is this differential sharing of attributes instead of an all-or-none criterion that distinguishes members from non-members of a category.

There is a second type of differential sharing of attributes. This differential sharing is found among the members within the category. A member with more attributes shared with other members within the category is more typical than a member with fewer attributes shared with other members of the category. A more typical member also has fewer attributes shared across categories than a less typical member. This differential sharing of attributes gives rise to typicality.

The point where the two types of differential sharing meet is often a fuzzy area. In other words, the least typical members of a category and some non-members are difficult to distinguish. Thus the probabilistic view on the whole more adequately deals with the problems that the classical view cannot.

Alongside the probabilistic view is the exemplar view of categories (Smith & Medin, 1981). Briefly, the exemplar view holds that people store examples during learning. New examples are classified by "computing" prototypes and determining the similarity of the novel example to the newly constructed prototypes. In other words, the central tendency is abstracted at the time of retrieval rather than at the time of storage or initial encoding as in the probabilistic view. There are a number of studies that run the prototype model and exemplar model in head-to-head competition (Barsalou & Medin, 1986; Estes, 1986; Medin & Ross, 1989 etc.). The results so far have generally been inconclusive.

The probabilistic view is now seen to exhibit a number of problems. Medin (1989) identified five local problems. 1) Prototype theory treats concepts as context-independent. But Roth and Shoben (1983) found that typicality judgements vary as a function of particular context. 2) Prototype theory implies that the only information abstracted from categories is the central tendency, thus information concerning category size, the variability of the examples and correlation of attributes would be discarded. 3) Barsalou's work (1985, 1987) shows that goal-derived categories such as "foods to eat while on diet" and "things to take on the trip" do not have prototypes but ideals. The typicality is not assessed by the similarity to an average or prototype but rather by similarity to an ideal. 4) Medin and Shoben (1988) note that the typicality of combined concepts cannot be predicted from the typicality of the constituents. 5) Prototype theory implies the constraint of linear separability of categories. But the constraint was not observed in classification learning experiments

(Kelmer-Nelson, 1984; Medin & Schwanenflugel, 1981).

Murphy and Medin (1985) and Medin (1989) also identified two global problems with the similarity-based categorization theories, including the prototype theory. "One is that probabilistic view theories do not say anything about why we have the categories we have." "The second central problem is with the notion of similarity. Do things belong in the same category because they are similar, or they seem similar because they are in the same category?" (p.1473). It is true that prototype theory does not deal with perhaps the most central issue of concept formation: why do we have the concepts we have and not others? or why do we select certain attributes to form concepts, for objects have far more attributes than those selected and any two objects have similarities on numerous dimensions that are simply not attended to by the cognitive system? There must be a set of constraints to explain the selection of attributes.

### 1.2.3 Quine's view on similarity

Quine ( 977) saw the problem of similarity as an explanation of categorization. He postulated an innate standard of similarity. But this innate standard of similarity is possessed not only by humans but also by other animals. Furthermore, this innate standard of similarity does not have an intellectual status. "Moreover, in this behavioral sense it can be said equally of other animals that they have an innate standard of similarity too. It is part of our animal birthright. And, interestingly enough, it is characteristically animal in its lack of intellectual status. At any rate we noticed earlier how alien the notion is to mathematics and logic." (p. 163) This innate standard enables us to perceive and discriminate the most superficial features of objects such as color. But such superficial features have very limited value in induction. "Color is helpful at the food-gathering level. Here it behaves well under induction, and here, no doubt, has been the survival value of our color-slanted quality space. It is just that contrasts that are crucial for such activities can be insignificant for broader and more theoretical science." (p. 166)

Indeed, perception of anything beyond the most superficial features demands higher than the innate standard of similarity. "Thus take color. Nothing in experience, surely, is more vivid and conspicuous than color and its contrasts. And the remarkable fact, which has impressed scientists and philosophers as far back as Galileo and Descartes, is that the distinctions that matter for basic physical theory are mostly independent of color contrasts. ... Color is king in our innate quality space, but undistinguished in cosmic circles. Cosmically, colors would not qualify as kinds." (p. 166) In other words, the distinctions that are made in the basic physical theory require a higher than the innate standard of similarity.

Quine believed that humans are doubly endowed with both a color-slanted quality space and the ingenuity to rise above it. "He has risen above it by developing modified systems of kinds, hence modified similarity standards for scientific purposes. By the trial-and-error process of theorizing he has regrouped things into new kinds which prove to lend themselves to many inductions better than the old." (p. 167) Finally, Quine argued for societal and individual progression from the innate to theory-based standard of similarity. "This development is a development away from the immediate, subjective, animal sense of similarity to the remoter objective of a similarity determined by scientific hypotheses and posits and constructs." (p. 171)

To summarize, similarity by itself does not explain categorization, for similarity must be defined by standards, which Quine suggested can vary from the innate, animal-like to the theory-based. Furthermore, both society and individuals develop from innate to theory-based standards of similarity. It may be useful to note here that Quine's argument will be a basis for developing a framework of knowledge development in this project, which in essence attempts to specify the mechanisms for deriving successively more theory-based constraints for the selection of attributes in categorization process.

### 1.2.4 Theory-based approach

In both Murphy and Medin (1985) and Medin (1989), a theory-based approach to study concept formation was proposed. Murphy and Medin compared their theory-based approach with a similarity-based approach, as presented in Table 1.1 on the next page.

| Aspect of conceptual theory | Similarity-based approach | Theory-based approach |
|---|---|---|
| Concept representation | Similarity structure, attribute lists, correlated attributes. | Correlated attributes plus underlying principles that determine which correlations are noticed. |
| Category definition | Various similarity metrics, summation of attributes. | An explanatory principle common to category members. |
| Units of analysis | Attributes. | Attributes plus explicitly represented relations of attributes and concepts. |
| Categorization basis | Attributes matching. | Matching plus inferential processes supplied by underlying principles. |
| Weighting of attributes | Cue validity, salience. | Determined in part by importance in the underlying principles. |
| Interconceptual structure | Hierarchy based on shared attributes. | Network formed by causal and explanatory links, as well as sharing of properties picked out as relevant. |
| Conceptual development | Feature accretion. | Changing organization and explanations of concepts as a result of world knowledge. |

Table 1.1 Comparison of Two Approaches to Concepts (Murphy & Medin, 1985)

As we can see, in every aspect of conceptual theory, while the similarity-based approach focuses on formal characteristics, the theory-based approach focuses on underlying explanatory principles. In another table (i.e. Table 1.2), Murphy and Medin identified five properties of theories and speculated about their roles in conceptual coherence. The table shows that existing theories impose a specific structure in interpreting reality and therefore also in selecting attributes or properties along which similarity of objects are compared.

| Property of theories | Speculation about role in conceptual coherence |
|---|---|
| "Explanations" of a sort, specified over some domain of observation. | Constrains which properties will be included in a concept representation. Focuses on certain relationships over others in detecting feature correlations. |
| Simplify reality. | Concepts may be idealizations that impose more structure than is "objectively" present. |
| Have an external structure--fit in with (or do not contradict) what is already known. | Stresses intercategory structure. Attributes are considered essential to the degree that they play a part in related theories (external structures). |
| Have an internal structure--defined in part by relations connecting properties. | Emphasizes mutual constraints among features. May suggest how concept attributes are learned. |
| Interact with data and observations in some way. | Calls attention to inference processes in categorization and suggests more than attribute matching is involved. |

Table 1.2 General Properties of Theories and their Potential Role in Understanding Conceptual Coherence (Murphy & Medin, 1985)

The basic tenet of the theory-based approach is as follows. Theories and prior knowledge act as a constraint for attribute selection, along which similarities are computed. Thus similarity is actually a by-product whereas theories and prior knowledge really offer the explanation for why we have the concepts we have. "The explanatory work is on the level of determining which attributes will be selected with similarity being as much a consequence as a cause of conceptual coherence" (p. 296)

Most recently, Medin, Goldstone and Gentner (1993) reviewed the status of similarity as an explanatory construct with a focus on similarity judgment. The idea is that for similarity to be useful, one must specify the ways or respects in which two things are similar, for as Goodman (1972) claimed, the "similarity of A to B" is an ill-defined and meaningless notion unless one can say "in what respects" A is similar to B. More formally, "The argument is as follows: Similarity is assumed to be based on matching and mismatching properties or predicates. Two things are similar to the extent that they share predicates and dissimilar to the extent that predicates apply to one entity but not the other. However, any two things share an arbitrary number of predicates and differ from each other in an arbitrary number of ways." (p. 255)

Medin et al. (1993) presented extensive evidence showing that similarity can change 1) with experience and 2) in context-specific ways. One evidence for similarity changes with experience is given by Gentner (1988) and Gentner and Toupin (1986). They observed that as children mature, their similarity judgment becomes increasingly based on more abstract, more relational and less superficial properties. Gentner (1988) reported that children give attributional interpretations to comparisons that adults interpret relationally. Given "a cloud is like a sponge", a 5-year old typically explains that "They both are round and fluffy" whereas an adult typically responds, "They both hold water and give it back later." Medin et al. (1993) said: "Although these developmental changes could stem from general processing differences, Gentner and Rattermann (1991) reviewed work in development of similarity and concluded that the relational shift can largely be accounted for in terms of changes in content and structure of knowledge." (p. 256)

For similarity changes to occur in context-specific ways, Barsalou (1982) demonstrated that similarity judgments vary when different particular contexts are specified. "For example, a snake and a racoon were judged much less similar when no explicit context was given than when the context of 'pets' was provided. The general idea is that the context tends to activate or make salient context-related properties, and to the extent that examples being judged share values of these activated properties, their similarity is increased." (p. 256)

But how are respects for similarity judgment specified? Medin et al. proposed that an important source of constraints derives from the similarity comparison process itself. First, similarity comparisons involve bringing aspects of entities into correspondence. This is called alignment, a dynamic process driven by multiple (global) constraint satisfaction. What gets aligned is not fixed a priori but depends on the particular comparison. Furthermore, the entities being compared mutually constrain the features that are activated or inferred. In a word, the constraints are derived in the process of comparison when the entities are set in a specific context.

Medin et al. (1993) conducted three experiments to test the idea that constraints are derived from the comparison process. In the first experiment, stimulus B (visual forms) is either compared with A alone or with C alone. The aim was to show that the properties attributed to stimulus B depend on whether it is being compared with A or C. The stimuli were constructed in such a way that a property attributed to B in an A-B comparison is incompatible with a property attributed to B in its corresponding B-C comparison.

The second experiment tested the idea of asymmetries in similarity comparisons. The idea is that in conceptual entities, only a subset of properties may be activated in comparison. In such comparisons, properties of the base or standard are more likely to become activated than properties of the target. Thus the common properties listed when A and B are being compared might be more closely associated with B when A is being compared with B, the base, and more closely associated with A when B is being compared with A, which is the base.

The third experiment examined the possibility of comparison-defined respects by presenting subjects with separate-context and combined-context comparisons. The separate-context presented A and B comparison, and B and C comparison separately. In the combined-context, both pairs are presented in the same context. The prediction is that in a separate-context, A and B may be rated low in the similarity scale. But in a combined-context where B and C are also presented, the similarity rating of A and B may be boosted. For example, presenting a black to red comparison in the same context as the black to white comparison may substantially increase the rated similarity of black to white.

The results of all three experiments supported the idea that constraints are derived in the similarity comparison process on the basis of specific contexts and that stimuli being compared mutually constrain the activation of properties for similarity comparison.

### 1.2.5 Summary

This review stresses two points in the study of concepts. The first point is that concepts and categories exhibit a set of characteristics called prototype effects. It should be particularly pointed out that the prototype theory has two claims. The first is that it embodies the insights that concepts have a family resemblance structure, degrees of typicality and prototypes. These are the properties of categories which the classic theory is unable to account for. The second claim is the prototype theory's own account of these properties. The ideas that categories are organized around prototypes by similarity judgment and that prototypes are formed by abstracting central tendency through maximizing the within-group similarity and minimizing the between-group similarity were once regarded as a good theory of concept formation. However, the prototype theory cannot adequately account for these properties. The inadequacy is twofold: 1) "similarity" is too unconstrained to ground cognitive processes such as categorization, and 2) a category construction model designed according to the idea of central tendency does not produce family resemblance categories (Medin, Wattenmaker & Hampson, 1987). The prototype theory is now seen as only offering a constraint for categorization theories (Lakoff, 1987). That is, it is known as a fact that most natural categories have a family resemblance structure, and that any theory that claims to explain concept formation should be able to generate categories which exhibit the family resemblance structure.

The second point that this review stresses is the fixing of the respects for determining similarity. Philosophers like Quine (1977), Goodman (1972) and

Kornblith (1993) all agreed that similarity must be constrained before we can use it as a construct for theories of categorization. Medin and his co-workers wrote a series of articles in this area, arguing for the need to specify respects and exploring ways to fix respects (e.g. Murphy & Medin, 1985; Medin, 1989; Medin, Goldstone & Gentner, 1993). We are still far away from building a model which specifies the necessary constraints for similarity comparisons in various contexts. Medin et al. (1993) argued for deriving constraints from the comparison process. However, this may not be appropriate. The comparison process is a cognitive operation in which the cognitive system with certain internal conditions interacts with the stimuli in which constraints are derived and applied for similarity judgement. But they are derived with conditions which cannot be captured within the comparison process, for these conditions are brought to the comparison process with the cognitive system. So for "A cloud is like a sponge", a child may explain "They both are round and fluffy" whereas an adult would typically respond "They both hold water and give it back later." The difference in response should not be looked for in the comparison process but in the different internal conditions or knowledge states of child and adult.

Since constraints seem to be generated in the interaction between the cognitive system and stimuli in the comparison process, one approach is to look at the interacting parties and the interaction process. At least for conceptual stimuli, the internal conditions may be the result of the interaction of two variables: the pre-existing knowledge of the domain and the goal of making the similarity comparison. The other party of the interaction is a set of stimuli. If the stimuli are visual forms, with no knowledge depth to them, no pre-existing knowledge is activated, but only what Quine called an innate similarity standard is activated. In cases of conceptual stimuli, such as "cloud" and "sponge", the domain knowledge and experience are activated. Thus people with knowledge and experience at different levels may see different similarities between the two stimuli. Furthermore, people with the same domain knowledge and experience may see different similarities if their goals are different. We will describe in detail the variables as well as their interaction in the following chapters.

The approach of looking at the interacting parties and the interacting process is consistent with Quine's idea of progression from the innate similarity standard to theory-based similarity standard and with Murphy and Medin's (1985) argument for roles of theories in conceptual coherence. However, to work with the theory-based approach, we need a general framework of knowledge, which should account for the source of data to be categorized and specify mechanisms on how constraints are derived from successively higher order theory, since theoretical knowledge exists on multiple levels. Chapter 2 will present such a framework.

## 1.3 Category Construction Models

Since the family resemblance principle was proposed in the mid-1970s (Rosch, 1975a), family resemblance sorting (hereinafter FR sorting) has been used as a test criterion for theories of concept formation. That is, if most natural categories exhibit the family resemblance structure, category construction models should be able to generate family resemblance categories (hereinafter FR categories). A number of models of category construction have been developed to generate partitions that maximize the within-category similarity and minimize the between-category similarity. In this section, we will review three types of models that generate FR categories. They are the similarity-based clustering models, Anderson's rational model, and the two-stage model.

### 1.3.1 Similarity-based clustering models

These models were developed in statistics and pattern recognition, where the family resemblance principle was applied. In these models (Anderberg, 1973; Massart & Kaufman, 1983), similarity on the dimensions/attributes of the exemplars are represented in terms of distance in multidimensional space. The dimensions correspond to the dimensions/attributes of the exemplars and the overall similarity between objects is judged by the average distance in the multidimensional space. Thus, similarity is an inverse function of the distance. To form clusters with exemplars that are close together in the multidimensional space, algorithms were developed. Similarity-based clustering can create hierarchical or non-hierarchical categories. The former are created either by first treating each exemplar as a category and then combining exemplars similar on the specified dimensions, or by first treating all exemplars as one category and then splitting them into subcategories based on the semantic distance among the exemplars. The latter, however, are created by recalculating the prototype each time when new exemplars are assigned to the category based on the exemplars' similarity to the prototype. These models have not been proposed as psychological models. However, the basic idea is the same as the probabilistic theory of concepts.

### 1.3.2 Anderson's rule-based rational model

While the similarity-based clustering models were proposed as statistical tools, John Anderson (1990, 1991) proposed a rational model of category construction which claims to be a model of human categorization behaviour. His model is based on maximizing the inference potential of categories. The basic idea is that since we can predict unknown features of an object by the very knowledge of the object's category membership, it is more advantageous to create categories that give us maximum predictability.

In developing an algorithm to create categories with maximum predictability, Anderson specifies the task in the following terms: "The basic goal of categorization is to predict the probability of various unexperienced features of objects. The situation can be characterized as one in which n objects have been observed, they have an observed feature structure Fn, and one wants to predict whether a particular object will display some value j on dimension i unobserved for that object. The ideal way to do this would be to consider all the different ways that the objects seen so far could be broken up into categories, determine the probability of each such partitioning, and use this to weigh the probability that the object will display a particular feature if that were the partition." (1991, p.411) The problem with trying to calculate this quantity is that the number of partitions of n objects grows exponentially as the number of objects increases.

An alternative is an iterative algorithm, in which new exemplars are considered incrementally and classified into the category that maximizes the predictability of the resulting partitioning. Two kinds of probability are calculated for each exemplar: the probability of the new object coming from existing categories (Pk) and the probability of creating a new category (Po). The new object is assigned to existing categories if Pk is greater than Po, or to the new category if Po is greater that Pk. Anderson defended the iterative algorithm, arguing that "people need to be able to make predictions all the time not just at particular junctures after seeing many objects and much deliberation." (1991, p.412)

Simulations were run to test the iterative algorithm. Anderson compared the categories thus generated with the results given by a wide range of models including empirical experiments and simulations. The comparison showed that his model will construct FR categories.

### 1.3.3 Empirical studies and the two-stage model

Only a few experiments have employed sorting tasks to evaluate category construction theories (Ahn & Medin, 1992). Imai & Garner (1965, 1968) ran such experiments. The finding is that people tend to sort exemplars on the basis of values along one dimension. Of particular interest and relevance to this project is a study by Medin, Wattenmaker and Hampson (1987).

Medin et al. (1987) set up a series of experiments based on the family resemblance principle. "According to this principle, sorting should be organized around exemplars that are prototypical of potential categories. In Rosch's words the idea is 'that potential prototypes will tend to become centres of categories in free sorting' (Rosch, 1975b, p. 196). That is, if we construct artificial categories by selecting prototypes and generating examples to create a family resemblance structure, then these same categories should be reproduced when people are allowed to construct their own categories from these examples." (p.244) Each experiment has two sets of exemplars around two prototypes. Each exemplar deviates from its prototype in one out of four dimensions. The abstract notation of stimuli used in Medin et al. is as follows.

| | D1 | D2 | D3 | D4 | | D1 | D2 | D3 | D4 |
|---|---|---|---|---|---|---|---|---|---|
| E1 | 1 | 1 | 1 | 1 | E6 | 0 | 0 | 0 | 0 |
| E2 | 1 | 1 | 1 | 0 | E7 | 0 | 0 | 0 | 1 |
| E3 | 1 | 1 | 0 | 1 | E8 | 0 | 0 | 1 | 0 |
| E4 | 1 | 0 | 1 | 1 | E9 | 0 | 1 | 0 | 0 |
| E5 | 0 | 1 | 1 | 1 | E10 | 1 | 0 | 0 | 0 |

Table 1.3 Abstract Notation of Stimuli Used in Medin, Wattenmaker, and Hampson's Experiments 1, 2, and 3 (1987).

D1 to D4 are the four dimensions. E1 to E10 are two sets of exemplars. E1 is the prototype of set one and E6 that of set two. Two values of each dimension are represented by 1 and 0. According to the notion of family resemblance, subjects were expected to maximize the within-category similarity and minimize the between-category similarity, thus sorting the exemplars into two groups represented by the two prototypes. Medin et al. were surprised to find that for the first half of the experiments, subjects used only a single dimension in sorting. Family resemblance was not observed. In the second half of the experiments, information that brought out interproperty relationships was provided, which allowed integration across component dimensions. Only then was the family resemblance observed.

More recently, Ahn and Medin (1992) proposed a two-stage model for category construction. "The general notion of the model is that when faced with probabilistic structures, people construct a simple core or primary basis for classification and then adjust for examples that do not conform to the core." (p.88) Ahn and Medin say that the two stage model can readily explain Medin et al.'s (1987) unidimensional sorting results. "According to the two-stage model, these exemplars do not even have to pass through the second stage of the model to be classified into two groups because all the exemplars consist of binary values. Whichever dimension is selected as the most salient one, exemplars with characteristic values of a contrasting category on the salient dimension will be grouped with the members of the contrasting category, resulting in 1-D sorting." (p.89) Thus for example, if D1 is chosen as the basis for sorting for the exemplars in Table 1.3, E1, E2, E3, E4 and E10 would be in one group and E6, E7, E8, E9 and E5 in the other, despite the fact that E5 and E10 each has three dimensions similar to their respective group.

To make the subjects go through the second stage, Ahn and Medin used trinary values with the intermediate value 1 between the two prototypic values, i.e. 0 and 2 (see Table 1.4 on the next page).

| | D1 | D2 | D3 | D4 | | D1 | D2 | D3 | D4 |
|---|---|---|---|---|---|---|---|---|---|
| E1 | 0 | 0 | 0 | 0 | E6 | 2 | 2 | 2 | 2 |
| E2 | 0 | 0 | 0 | 1 | E7 | 2 | 2 | 2 | 1 |
| E3 | 0 | 0 | 1 | 0 | E8 | 2 | 2 | 1 | 2 |
| E4 | 0 | 1 | 0 | 0 | E9 | 2 | 1 | 2 | 2 |
| E5 | 1 | 0 | 0 | 0 | E10 | 1 | 2 | 2 | 2 |

Table 1.4 Abstract Notation of Set A Used in Ahn and Medin's Study (1992)

In this set, if we still use D1 as the most salient dimension, E5 does not have value 2 and E10 value 0 to put them in their respective contrasting groups. Instead, in the first stage, E1, E2, E3 and E4 are classified as one category and E6, E7, E8 and E9 the other. "In the second stage, because E5 is more similar to E1, E2, E3 and E4 than to E6, E7, E8 and E9, it is categorized with E1, E2, E3 and E4. Similarly, E10 is categorized with E6, E7, E8, and E9. Therefore, as a result of the second stage, the model generates FR categories for this set." (p.90) The results showed that the two-stage model can produce FR categories.

What do we make of the two empirical studies? Medin et al. (1987) study showed that people do not form prototypes by abstracting central tendency through maximizing the within-group similarity and minimizing the between-group similarity and making an overall similarity judgement in sorting of the exemplars. In the absence of appropriate constraints, they produced sorting based on the values of a single dimension. In the two-stage model (Ahn & Medin 1992), apart from the fact that two categories must be produced, an additional constraint was put in by having an intermediate value on any chosen dimension for stage one sorting and having the same values in the other three dimensions with the prototype of the group, so that in stage two sorting the exemplar would be assigned to its own group.

The problem is that natural categories are not likely to have such a delicate arrangement of values. The robustness of natural categories in exhibiting family resemblance would suggest that FR sorting should be observed across a wide range of stimulus conditions including inequality of salience among the dimensions (Medin et al. 1987), and value arrangement. In fact, categorization must be almost insensitive to these conditions in producing FR categories in a natural environment. What this analysis tells us is that we do need constraints to produce FR categories but we should mainly look for internal constraints in the cognitive system doing the sorting, not the external constraints in the arrangement of stimuli.

A related problem is that both studies mainly used visual forms as stimuli with no knowledge depth to them. With such stimuli, only the innate similarity standard is activated in the subjects. Consequently, no internal constraints based on the pre-existing knowledge can be created other than the perceptual constraints that make up the innate similarity standard.

## 1.4 The Thesis Project

The thesis has two phases. First, a theoretical framework of knowledge development is constructed to account for the progression from an innate similarity standard to successively higher order theory-based similarity standards, a progression first proposed by Quine (1977). The framework will in effect specify how constraints are derived based on the successively higher order theory. There is an additional dimension to the account of the progression in the framework. That is, categorization based on the similarity standard at one cognitive level is seen as an integral stage in the development of theoretical knowledge at the next higher cognitive level, which in turn is the basis for deriving constraints for a higher standard of similarity.

The framework is developed to provide a systemic context for the study of concept formation. A theoretical framework differs from a model in that it does not attempt to construct the entire mechanism to account for knowledge development. For instance, we will not deal with the issue of how schema and mental models are constructed with concepts. The framework we will see presents a set of variables and the dynamic relations which will enable us to give a coherent account for deriving constraints for similarity judgement.

The second phase of the project developed an adaptive model of category construction operating within the framework of knowledge development and capable of generating FR categories. The model focuses on deriving internal constraints for categorization through a preference-rule based interaction among the three variables: the innate perception of similarity, the pre-existing knowledge at the highest cognitive level and the goal for the categorization. The constraints thus derived help to form prototypes by setting a perspective for selecting and weighing the attributes. The same constraints will be applied in determining the objects' membership of categories. According to this model, the family resemblance structure of the categories results from adaptation or compromise of the adopted perspective in order to subsume sufficient data for achieving the goal.

Two experiments were run to test the adaptive model of categorization. Specifically, the two experiments used the same two types of stimulus sets as in Medin et al. (1987) study and in the two-stage model (Ahn & Medin, 1992). The first stimulus set is shown in Table 1.3. As mentioned in the literature review (pp. 21-22), FR categories are not observed with the stimulus set in Table 1.3 in Medin et al. (1987). The second stimulus set is the same type as Set B of the two-stage model (Ahn & Medin, 1992, p. 92) which, according to the two-stage model, cannot generate FR categories. The adaptive model uses internally derived constraints and predicts that FR categories can be generated with these stimulus sets.

Ideally, such experiments should be conducted in knowledge-rich domains such as classical physics and biological taxonomy, where knowledge has a multi-level structure and where concept formation at any level has relatively clear prerequisite knowledge at the level immediately below. In such an environment, we could investigate concept formation at two cognitive levels. We could observe how constraints are derived in the interaction among the innate perceptual principles, the pre-existing knowledge-based principles and the goal. We could also show how categorization at one cognitive level leads to new theoretical knowledge which provides the basis for deriving constraints at a higher cognitive level. However, actually this study contended itself with investigating the effects of pre-existing knowledge and goal in generating internal constraints on similarity judgement. The experiments employed stimulus material for the creation of artificial categories. An artificial pre-existing knowledge base related to the exemplar sets was created to allow for deriving internal constraints. Although the experiments in this thesis work are not able to show the dynamic relations between the two cognitive levels, they do test the basic assumption that appropriate constraints for similarity judgement are derived internally with pre-existing knowledge and goal.

The general organization of this work is as follows. The framework of knowledge development and the adaptive model of category construction are presented in Chapter 2. Chapter 3 discusses the features of concepts and their cognitive effects. Chapter 4 reports on two experiments carried out in this project. Chapter 5 discusses the implications of the framework in relation to designing effective instruction for promoting conceptual system change and implications of the adaptive model for designing instruction for concept teaching. Finally in Chapter 6, future research in the area is outlined together with a summary of the project.

# CHAPTER 2

# A THEORETICAL FRAMEWORK OF KNOWLEDGE DEVELOPMENT AND A CORRESPONDING ADAPTIVE MODEL

## 2.1 Concept Representation and Concept Formation

For a long time, study of concepts has focused its attention on the concept representation issue. The question asked is: How are concepts represented in the mind: as sets of features that are necessary and jointly sufficient, or in the form of prototypes or sets of exemplars? The question of formation was answered by the similarity principle. That is, objects with similar features are grouped together as categories (for a review, see Smith & Medin, 1981; Lakoff, 1987).

Studies on concept representation made their contributions. For example, the feature theory and concept distinctiveness were associated with the classical view, and the family resemblance principle and typicality were associated with the prototype theory. By the 1980s, the classical view was largely discredited. Research efforts were then concentrated either on comparing the prototype theory with exemplar theory or on looking for the sources of family resemblance and typicality, generally referred to as "prototype effects" (Lakoff, 1987). Neither kind of research has met with much success. The head-to-head competition between the prototype theory and exemplar theory was not conclusive. The search for an account for the prototype effects did not make much progress. Rosch gave up her earlier claim that prototype effects directly mirror category structure and that prototypes constitute representations of categories. Instead, she regarded prototypes as a constraint to processing models and representation models (Rosch 1978).

In fact, family resemblance and typicality are representational characteristics that concepts exhibit. Of course, to say that concepts have or exhibit a set of properties has not answered the question of why they exhibit these properties. The "why" question is at the concept formation level, not at the representational level. However, the representational properties do constitute a powerful constraint for theories that attempt to explain concept formation. That is, concepts formed according to a certain theory should also exhibit the properties of family resemblance and typicality.

As mentioned in the introduction, family resemblance and typicality can be seen as two types of differential sharing of attributes. The first type of differential sharing, i.e. family resemblance, requires that a member of a category share more attributes with other members within the category than with non-members across categories. From the category's point of view, a category must maximize similarities within the category and minimize similarities between categories in order to achieve distinctiveness. The second type of differential sharing of attributes, i.e. typicality, exists among the members within the category. This is where more typical and less typical members of a category are distinguished. The advantage of seeing family resemblance and typicality both as distinct kinds of differential sharing of attributes is that we can ask two questions at the concept formation level. 1) Why are a set of attributes selected and shared to such a sufficient degree that a category acquires its existence? (In fact, this is equivalent to Medin's question of why we have the categories we have.) 2) Why are some attributes more shared than others? Or why do some members have more attributes of the category than others?

To answer these questions and account for some other properties of categories that we will see later on, we need to go beyond the representational level and overcome the deficiencies of the theory-based approach. We need a comprehensive framework of knowledge development as the systemic context for categorization operations.

## 2.2 The Framework of Knowledge Development

A semanticist once said that it is impossible to know everything about a tree so that we can make unqualified truth statements about the tree. To have a complete knowledge of a tree, we have to know more than what kind of tree it is, how old it is, where it is growing, etc. The present state of the tree is attained as a result of the interaction of many factors such as genes, the local climate, the soil on which it grows, and human activities in its surrounding which may have produced pollution that affects its growth one way or another. Its genes have a long history of evolution. The local climate and soil are part of larger systems. In short, to know everything about a tree in order to make unqualified truth statements about a tree, one would need to know the whole universe.

Bronowski (1973) expressed a similar view when he said: "One aim of the physical sciences has been to give an exact picture of the material world. One achievement of physics in the twentieth century has been to prove that aim is unattainable." "We are here face to face with the crucial paradox of knowledge. Year by year, we devise more precise instruments with which to observe nature with more fineness. And when we look at the observations, we are discomfited to see that they are still fuzzy, and we feel that they are as uncertain as ever. We seem to be running after a goal which lurches away from us to infinity every time we come within sight of it."

Two assumptions can be drawn from these citations. First, a domain reality holds infinite potential for cognitive growth. Second, cognitive growth has multiple levels. The cognitive levels are clearly implied in Bronowski's paradox of knowledge. That is, when we have arrived at a new theory that solves our existing problems, we discover new things that cannot be accounted for by the theory and hence new problems arise. Each cycle can be seen as a cognitive level, in terms of which a theoretical statement has anchored truth. Furthermore, the truth value of competing theoretical statements are helpfully falsifiable through application to problem solving at an appropriate cognitive level. All of this should be captured by a cognitive model that claims to describe knowledge development.

### 2.2.1 The cognitive levels

First, we propose a multi-level cognitive landscape with 3 strata: basic levels, micro-levels and macro-levels (see Fig. 2.1 on the next page).

Macro-levels

|

Basic levels

|

Micro-levels

Fig. 2.1 Levels of Cognition

It may be a continuum from the basic levels to the micro and macro levels. But in order to characterize the continuum in some way, it is convenient to break it into discrete levels. The basic levels refer to the cognitive landscape of the real world within the range of the most direct human perception and interaction. Humans can perceive an array of objects such as plants and animals, and observe the interaction among them, interact with them and observe the effects of the interactions directly. Through the observation and interactions, we form concepts, models and theories, which explain the phenomena and guide our further interaction with the environment of the basic level world. For example, folk biological knowledge is generated in the basic levels. Brent Berlin (1978) defined the study of ethnobiologists as a study of categorization in the biological domain at the basic levels. "Ethnobiologists have focused on the biological kingdom (or those aspects of the biological kingdom that are readily visible to humans without the aid of microscopes) as the most inclusive category for the productive study of folk biological knowledge - in ethnobotany, the world of plants, in ethnozoology, the world of animals." (Rosch & Lloyd, 1978, p. 11)

But as human understanding deepens, we come to a point where phenomena at the basic level world cannot be explained other than by speculating (e.g. by invoking supernatural entities). Examples of this kind include speculations about causes of infectious diseases before micro-organisms could be seen through a microscope. This is the point where direct human perception has come to the limit at one end bordering the micro-level world. We do not see directly with our eyes bacteria, cells, atoms, etc. or observe our interaction with these entities.

Conceptualization in the micro-level world is far more complex than that in the basic level world. First of all, we have to rely on instruments to observe the micro-world (the entities and interactions), arrange for our interaction with the entities there and observe the effects of the interaction, so that we can assess our conceptualization. Secondly, to solve any problems that can be felt at the basic level world, the relevant variables in the micro-world increase rapidly. Thus there are more categorizations to be made and more relationships and interactions to be investigated than a problem solvable at the basic levels.

There is also an upper limit of direct human perception and interaction. For example, we have to construct a model of an object larger than directly observable by piecing together the observed parts of the object or the parts we have interacted with. Examples of macro conception are maps or models of a mountain, a country and the globe. This is the macro world. The conceptualization of the macro-world is a synthesizing process based on the conceptual categories at the basic- or micro-levels. Here mental models are built and a certain area of phenomena can be coherently accounted for.

To appreciate the relationship between the range of direct perception and the complexity of conceptualization, we need only to note that we build models of the micro and macro worlds for teaching purposes by enlarging the micro world (e.g. the cell structure of a plant) and reducing the macro world (e.g. the model of a mountain, or the globe) to the basic level size in order to help learners conceptualize the domains not directly observable to humans.

A more micro-level conceptualization enables more macro-level synthesis and a mental model at the more macro-level would enable the cognitive system to perceive more of the domain reality and generate more fine-grained information for further micro-level conceptualization.

### 2.2.2 Three stages to conceptualization

To adequately answer the questions we have raised, we need to look at how the conceptualization of a domain at a particular cognitive level may be arrived at. Let us postulate three stages in conceptualizing phenomena in a particular domain of the real world. These stages are: 1) domain reality; 2) experience field; and 3) conceptual field (see Fig. 2.2).

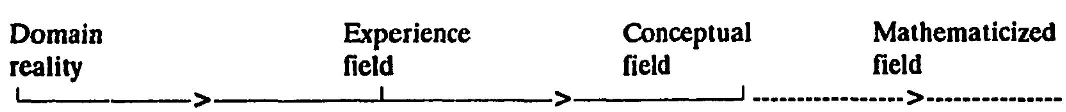


Fig. 2.2 Stages of Conceptualization

The domain reality always has an unperceived portion which is infinite and simply outside our consciousness. An example of this infinite unperceived realm is the disease of AIDS. The disease had existed for some time before we came to notice it. It was then part of the infinite unperceived reality.

With regard to the experience field, we are aware of or have experienced far more of the world than what has been conceptualized. For example, we have experienced far more variations of color, emotion, taste, weather, etc. than what the existing categories need to capture and have captured. To continue our example of AIDS, there was a period of time starting from the moment when the symptoms of the disease first aroused the suspicion of doctors to the time when HIV virus was identified and the way it works in the human body was roughly understood. During this period of time, we experienced the disease but did not have a mental model of the disease.

Finally, within the conceptual field, concepts, conceptual systems and theories constitute our mental model of a particular domain of the real world. We are not concerned with differences among the disciplines of sciences in terms of levels of consistency of conceptual systems. All we want is to delineate that part of cognition where reasoning is possible, because that is where concepts are needed and formed. A similar distinction between experience field and conceptual field is made by Jackendoff (1983), and the distinction between apprehension and comprehension in Kolb (1984) corresponds to that between experiences and concepts respectively.

### 2.2.3 The framework

If we put together the levels of cognition and stages of conceptualization in the form of polarcoordinates in a Cartesian plane, we have a framework to help us find answers to the questions we raised above (see Figure 2.3).

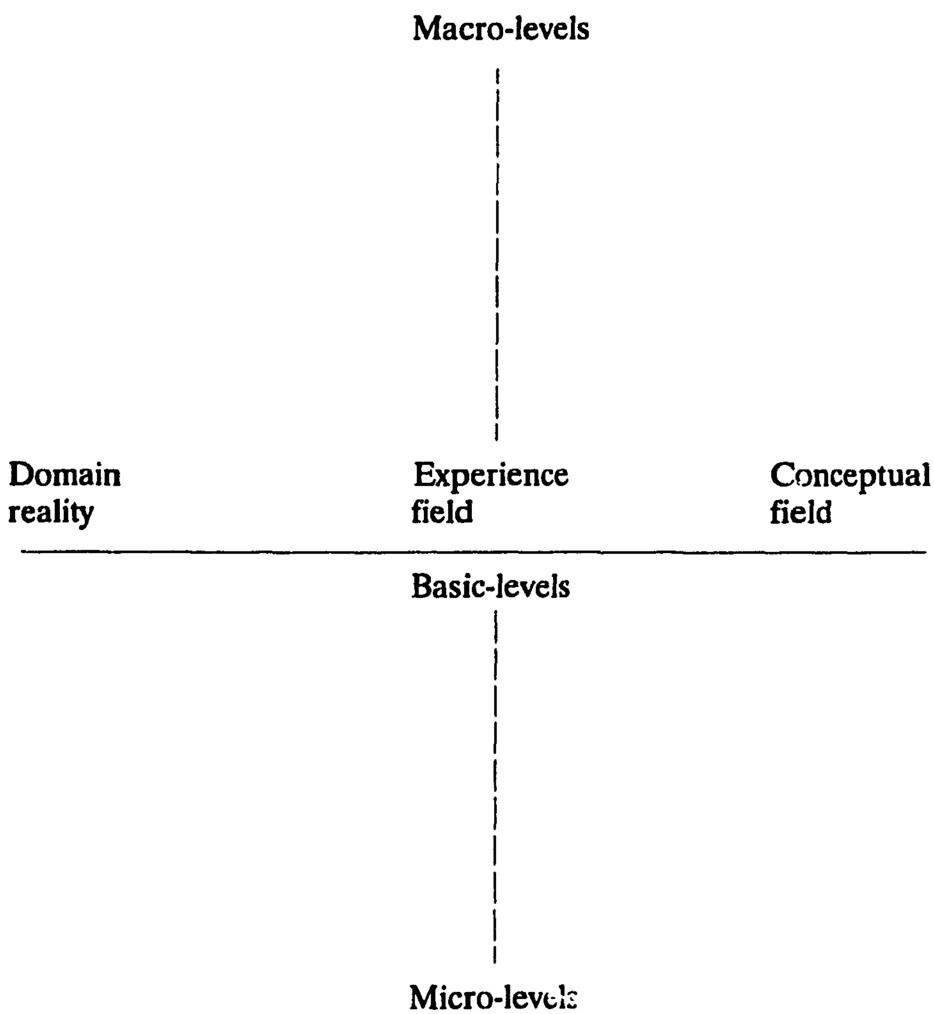


Fig. 2.3 The Framework of Knowledge Development

This multi-level framework is intended to show two points. The first point is that experiencing and conceptualizing start from the basic levels and develop in the micro and macro directions. We refer to the more basic levels as lower cognitive levels and more micro and macro levels as higher cognitive levels. Second, concepts have an inherent range of applicability beyond which, if used at a higher cognitive level, they become inadequate. To achieve the goal at a higher cognitive level, the cognitive system has to reconceptualize the experience field and often even has to wait for more experience by exploring the unperceived domain reality. This account reveals the intrinsic link among the prototype effects inside the conceptual categories, experience outside concepts and the unperceived domain reality which obviously remains outside experience.

Let us see how this framework operates (See Fig. 2.4). The vertical and horizontal lines in the figure represent the same cognitive levels and stages of conceptualization as shown in Fig. 2.3 on the next page.

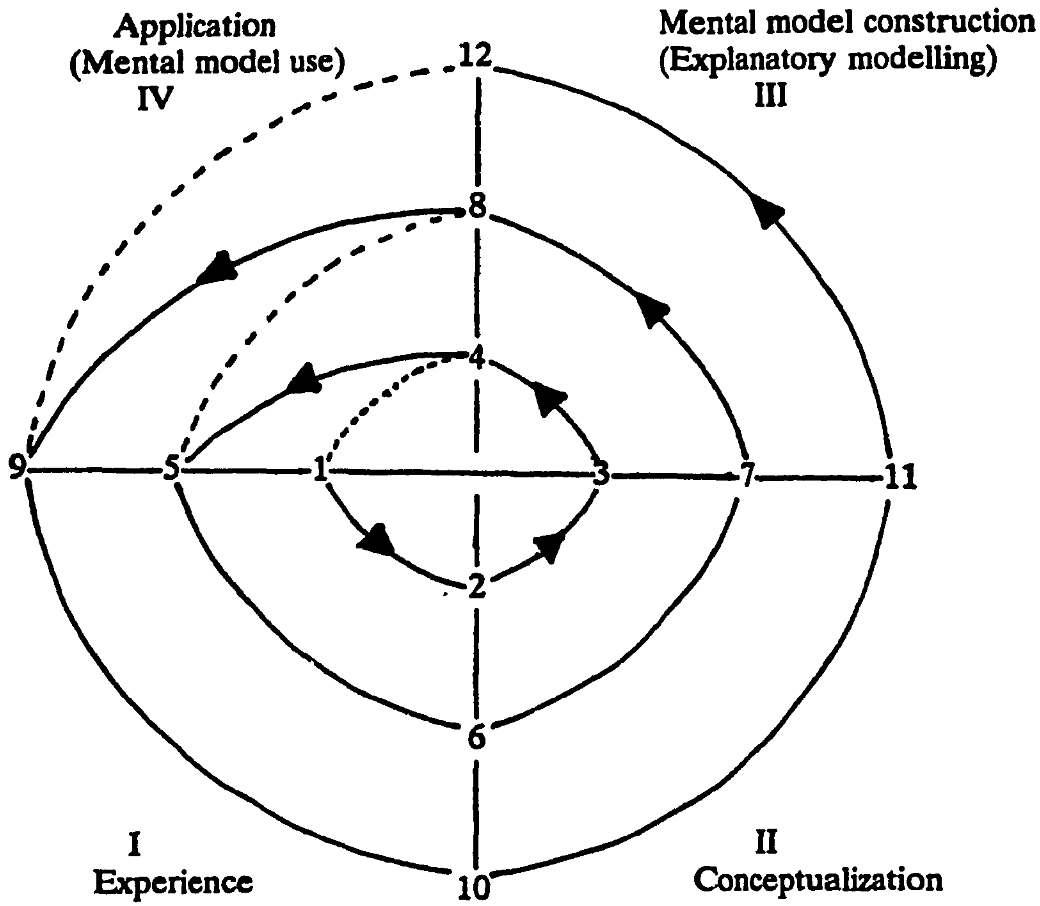


**Fig. 2.4 The Operation of the Framework of Knowledge Development.**

The four quadrants represent the four components of the framework. Quadrant one represents the experience stage, quadrant two, the conceptualization stage, quadrant three, the mental model construction stage (explanatory modelling) and quadrant four, the application stage (mental model use). Each number marks a point or milestone in the course of knowledge development. The line joining two points indicates a mental stage at a particular cognitive level. Each full circle, e.g. 1-2-3-4 including the broken line joining 4-1, represents a cognitive level. The circle runs counter-clockwise starting from the centre where the cognitive system perceives and interacts with a domain reality at a very low level. As the circle expands, the domain reality is pushed further left.

In this figure, points 1, 5 and 9 represent successive steps in bringing larger portions of a domain into awareness. That is, more of the domain is experienced. Also, information elements of finer grain size and their relations constitute data for more micro-level conceptualization. Points 2, 6 and 10 indicate this progression. Points 3, 7 and 11 indicate the successive expansion of conceptual systems subsuming an ever larger experience field. Finally, points 4, 8 and 12 situate the mental models representing the three levels of knowledge of the domain. Thus in the figure, we have three cognitive levels, each comprising four mental stages.

-- 1-2 Experience stage: This is a stage where a person observes and interacts with the environment of the real world. What can be experienced is largely determined by the pre-existing knowledge. As this is at a low cognitive level, the domain is experienced through direct perception and interaction. Problems of simple nature are encountered. At this stage, some aspects of the domain are experienced to a certain degree. There is always an unperceived part.

-- 2-3 Conceptualization stage: This is a stage where categories are formed. The conceptualization process is goal directed. Three variables, namely, innate perception, pre-existing knowledge and goals interact and compete in selecting attributes to be encapsulated in conceptual categories. The result of this process is that conceptual categories are formed and enter the rational thinking as operating units.

-- 3-4 Macro-conception: This is a stage where mental models and explanatory schema are constructed. Concepts are here put into relationships with one another in the model. The resulting conception achieves coherence in the experience field.

-- 4-1 Application: The broken line joining 4 and 1 indicates that the mental model formed at point 4 is adequate for prediction and solving problems encountered in stage 1-2.

-- 4-5 The mental model at point 4 is formed and is adequate for solving problems of stage 1-2. In the meantime, because of the mental model, cognitive activities including observation and interaction have been elevated to a new level, where the cognitive system can perceive new phenomena.

-- 5-6 Experience stage: This is the same stage as 1-2 but at a higher cognitive level. New phenomena of more micro-world nature are experienced. A new set of problems arise, for which the mental model at point 4 is inadequate. The fundamental inadequacy is often found in the very classification of the conceptual system in 2-3.

-- 6-7 Reconceptualization stage: The variables are the same as in 2-3 but at a higher cognitive level compared with 2-3. Two things are changed. First, the pre-existing knowledge is the mental model achieved at point 4. The reconceptualization is constrained by and therefore coheres with some principles of the pre-existing knowledge while rejecting others. The goals are more complex. Second, the interaction pattern of the three variables changes with goals and pre-existing knowledge exerting more influence on classification. In Quine's words, a new standard of similarity is attained.

-- 7-8 Macro conception: The new mental model is more powerful than the model at 4. Its concepts encapsulate more fine grained information and its synthesis is at a more macro level, subsuming a larger experience field.

-- 8-5 Application: Again, the broken line represents the adequacy of the new mental model for solving problems or performing cognitive tasks encountered in 5-6.

-- 8-9: In the meantime, with the mental model at point 8 as a scaffolding, the cognitive activities are elevated to a new high level, where new phenomena are observed. This is when what Bronowski calls the new uncertainties come into sight again and the goal of attaining the ultimate truth lurches toward infinity. A new cycle for yet a higher cognitive level starts, which will lead to a new mental model at point 12.

To summarize, in this framework, concepts are mental constructs conceived to organize experience with the environment and to form schema, theories and mental models to make sense of and guide our interaction with the domain environment. Through the interactions, new phenomena are revealed in new experience, which provides the basis for a higher level conceptualization and the restructured mental models, which in turn guide our interaction with the environment at a higher level. The cycle goes on.

Two points should be quickly added to this statement. First, one stage in this cycle is the condition for the next stage but does not necessarily lead to the next. Dogmatism and sometimes wilful dogmatism about a belief can prevent reconceptualization from taking place for hundreds of years. Lack of adequate methodologies can frustrate the efforts to test the validity of the reconceptualization. Second, when a new mental model is arrived at, the old is not necessarily abandoned. The new and old can be adequate for cognitive tasks at different cognitive levels in a domain.

One may have objections to the fact that the framework compartmentalizes mental stages. We may not in fact gather all the necessary experience before attempting to categorize available information and we may not form all the right categories before constructing mental models. And indeed we may not wait till we have a complete and adequate mental model before we try to solve problems with it. In a word, the feedback information may run across the mental stages as the work in each stage is being performed rather than after it is performed.

But note that the proposed framework tries to encompass mental models for solving problems at all cognitive levels, from a child's problem in getting a candy on a table too high for him to reach to problems in scientific research. This is necessary for capturing the dynamic relations between cognitive levels. If we focus on problems at a particular cognitive level, the model operates in the way as shown in Fig. 2.5 on the next page.

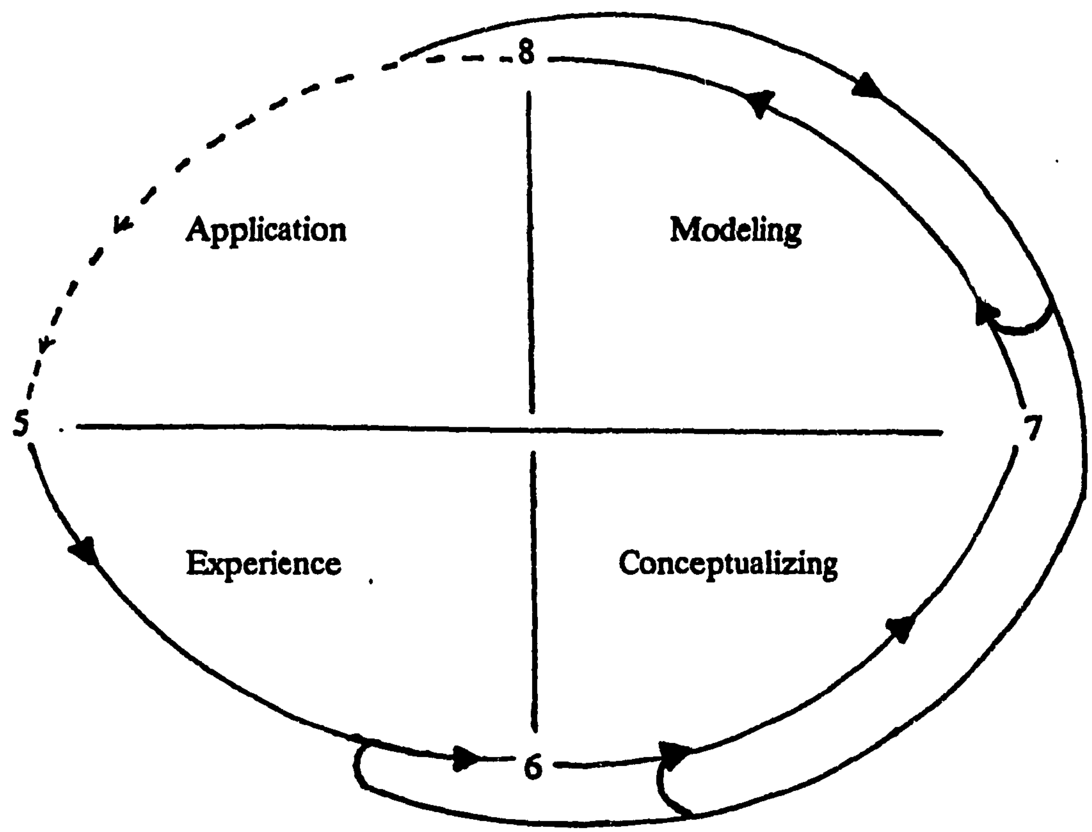


Fig. 2.5 Learning Sequence and Feedback Loops of a Single Cognitive Level

Here, the counter clockwise line represents the progression through the stages toward the construction of an adequate mental model for solving problems at 8-5, the part shown in Fig.2.4. However, the work is not accomplished at one trial. The clockwise line represents feedback running from the application stage to the three other stages. Depending on the feedback information, any of the three stages could be changed. The model could be restructured with existing categories (e.g. re-ordering a set of rules). In this case, the information feedback loop runs from application at 8-5 to 7-8. Some categories may have to be changed or additional categories may have to be created. Here, the feedback could run either from application or model construction at 7-8 to 6-7. In some cases, the cognitive system may need more experience in the domain and bring in more fine-grained information before adequate categories can be formed for the construction of the rule-based model at point 8. The information feedback loop in this case could be from any of the other three stages to 5-6. Eventually, the mental model will match the state of the domain environment at that particular level and the problems at that level can be solved. This is when we see the broken line finally pushes through to point 5 from 8.

## 2.3 An Adaptive Model of Category Construction

With the framework of knowledge development, we can now answer the question of how similarity is constrained. That is, the data (i.e. the phenomena perceived), the pre-existing conceptual model and goal are all inter-related in terms of cognitive levels. A conceptual model at a particular cognitive level enables the perception of data and formulation of goal at a particular cognitive level. The pre-existing conceptual model, goal and innate perception interact to derive constraints of similarity for categorization. The adaptive model works at a particular cognitive model within the framework. It specifies the process of attribute selection for forming categories with FR characteristics.

The model has three components: a data base, a preference rule-based interactive process inside the cognitive system with at least three variables (i.e. the innate perception, pre-existing knowledge and goal), and a negotiation process. The model operates in the framework of knowledge development.

**2.3.1 The data base**

The data mainly consist of new experience that an existing mental model enables the cognitive system to gain. In our framework (Fig. 2.4), for instance, the mental model of point 8 enables the cognitive system to expand the experience field from points 5 to 9. The new power of mental model at 12 over that of point 8 is largely derived from this inclusion of new experience with a larger portion and greater depth of the domain reality. (Of course, the cognitive system can also rework the same experience base to form a better mental model.)

This source of data has at least three characteristics. First, the new information is regarded as facts "out there" to be accounted for. It represents a new expansion of the cognitive system into the objective domain. Secondly, however, the data in fact are not entirely objective, as they are perceived with the existing theories, metaphors, narratives, and mental models. The new information survives the first screening of the cognitive system. This characteristic ensures that the new information is largely consistent with the existing knowledge. Thirdly, as the existing mental model constrains the construction of data, the data that would be categorized are within what Vygotsky (1968) called the "zone of proximal development". These characteristics of the data make it possible for the cognitive system to incorporate the data and generate a new, more powerful mental model.

### 2.3.2 The preference rule-based interaction process

In this process, three variables (i.e. the innate perception, pre-existing knowledge and goal) interact according to the preference rules (Jackendoff, 1983) to adopt an organization principle or perspective. This process inside the cognitive system explains the kind of structure that the cognitive system is likely to impose on the data and the depth to which the cognitive system is to process the data.

The innate perception The view that categories are formed by similarities that objects share among themselves is simplistic. To Medin (1989), similarity is only a by-product. The problems with the similarity-based approach are explained in Murphy and Medin (1985). Briefly, the similarity-based approach overlooks the fact that objects are similar on numerous dimensions or in many attributes. It does not explain why certain attributes are selected for measuring similarity. If stripe is selected as an important attribute, zebra would be more similar to a barber pole than to a horse (Medin, 1989). Without constraint, any two objects around us would have numerous similarities. For example, they both exist on the earth, both obey the law of gravity, both take up certain space and both can be named and looked at by humans, etc. The constraint is on the selection of attributes. Thus, the perception of similarity is not a simple issue as it was once thought. People with mental models at different cognitive levels can perceive different kinds of similarities, because they select different dimensions along which objects are compared. Similarity can be perceived, based on the more basic level conception of the objects (e.g. a sparrow is more similar to a bat than to a chicken) or on higher level conception (e.g. a sparrow has more similarities with a chicken than with a bat).

The innate perception refers to certain ways of perceiving we are born with. In Quine's words (1977), it is the innate standard of similarity. The innate perceptual principles must be invoked to explain why we group things according to proximity, size, etc. Jackendoff (1983) uses many examples from Wertheimer (1923) to illustrate preference rules. The simplest one involves the grouping of circles. Consider the following configurations:

| (a.) | (b.) |
|---|---|
| ooo oo | oo ooo |

Jackendoff says (a.) is most naturally seen as three circles to the left of two other circles and (b.) as two circles to the left of three. The word "naturally" suggests that grouping objects in the environment by proximity is one of the innate principles, though it may be a weak one, easily overridden by other principles in case of conflict. Suppose, we introduce the size of the circle to interact with the proximity.

| (c.) | (d.) |
|---|---|
| ooo OO | oo oOO |

In (c.) proximity and size reinforce each other, since the three small circles are close together and the two large circles are close together. The resulting grouping is therefore strengthened. In (d.), nevertheless the one of the small circles is near the large circles, so the principle of proximity and the principle of size conflict. The resulting intuition is ambiguous. Ullman (1979) also discussed some built-in perceptual principles.

Quine (1977) postulates a specific innate standard of similarity: "A standard of similarity is in some sense innate. This point is not against empiricism; it is a commonplace of behavioral psychology. A response to a red circle, if it is rewarded, will be elicited again by a pink ellipse more readily than by a blue triangle; the red circle resembles the pink ellipse more than the blue triangle. Without some such prior spacing of qualities, we could never acquire a habit; all stimuli would be equally alike and equally different." (p.162) If there is a set of innate perceptual principles, then we innately perceive certain environment inputs as more similar to each other than others, again when the pre-existing knowledge and goals are not involved. In fact, studies on classification, employing artificial categories, mainly test subjects' innate principles in perceiving similarities, for these studies exclude the pre-existing knowledge and goals from interacting with innate perceptual principles.

Categorization based on the innate perceptual similarities is observed in what is known as basic level categories such as chair and book (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). In our framework, the innate perceptual similarity-based categorization characterizes the conceptualization stage (stage 2-3 in Fig. 2.4) at a low cognitive level.

The pre-existing knowledge Pre-existing knowledge refers to the concepts, rules and principles in the "highest" mental model of the cognitive system. It has at least two roles in selecting and grouping attributes into categories. First, it is largely responsible for determining at what cognitive level one is to experience the domain reality. Someone who has a mental model at point 4 of our framework will experience the domain at a lower level whereas someone who has a mental model at point 12 will experience the domain at a higher level. Thus where the expert sees regularities with a mental model at 12, the novice may only see chaos at stage 5-6. Where the expert may detect problems, exceptions to rules and complex interaction of many variables at stage 9-10, the novice may experience order and coherence at point 4. If they are to formulate new concepts in the domain, their concepts must be at the different cognitive levels because they experience the domain reality with mental models at different cognitive levels in the first place.

The second role of the pre-existing knowledge is to guide and constrain the selection of the attributes by providing the knowledge-based similarity standard. For instance, with certain knowledge of biology, one would select warm blood and giving birth to live young as attributes whereas swimming and living in the sea are not selected as attributes. Thus a dolphin is more similar to a horse than to a shark and is classified as mammal rather than fish. Unless there is a major upset of the pre-existing knowledge structure, new concepts are formed on the basis of the knowledge in the existing mental model. For example, one's general pre-scientific knowledge of water such as the phase relations between water, ice and steam and other observable properties of water indicates that water is inanimate. This knowledge precludes the possibility that, in studying the chemical composition of water, one would hypothesize that cells might be the basic components. In case of a major upset of knowledge structure, the new theory is responsible for explaining not only the phenomena which motivated the conceptualization, but all the others that were previously explained by the pre-existing knowledge. Thus the constraint exerted by the pre-existing knowledge ensures a degree of coherence between the conceptual systems at two cognitive levels.

The goal The goal is formed when the cognitive system wants to explain the new experience, to account for the counter examples of known rules and principles, or to solve new problems. The pre-existing knowledge constrains goals, for it determines what kinds of goals can be reasonably entertained and attempted. However, since there is a need for new concepts, the pre-existing knowledge must be inadequate. The goal provides motivation and a target for new conceptualization. A more important role of the goal in selecting and grouping attributes is to enable the cognitive system to set up a feedback loop with the objective domain, for goals must be accomplished in the domain reality through appropriate effectors. The information from the feedback loop guides the concept formation process in the way Simon's ant is guided to its home (Simon, 1981), as illustrated in Fig.2.5. The goal thus ensures that new concepts are adequate for achieving the goals.

The innate perception produces weak organization principles (Jackendoff, 1983) for low order categorization. An example is categorizing stimuli based on their colors. The pre-existing knowledge overrides the weak innate perceptual principles when there is a conflict. Take the grouping of circles again. When judged by the innate perception only, oo o00 produces ambiguity because proximity and size are in conflict. However, suppose we know that small and large circles in this case are formed in two different chemical processes, we would put two large circles in one group and the three small circles in the other. In this case, the dimension selected for grouping, i.e. size, is knowledge-based. It is different from the size dimension selected by the innate perception when the pre-existing knowledge is not involved. It is more powerful and overrides the principle of proximity. Note that similarity is involved only after the selection of dimensions is determined.

Empirical studies also support this view. Chi, Feltovich, and Glaser (1981) noted that the basis for similarity appears to change with expertise. They compared the way novices and experts classified physics problems. Novices tended to classify them on the basis of superficial features whereas experts classified them on the basis of deeper underlying principles. Medin, Goldstone and Gentner (1993) cited a study by Kolstad and Baillargeon (1991) on knowledge effects in infants' generalization. Kolstad and Baillargeon found that in the absence of specific knowledge, generalization was based on overall similarity. When infants were given experience with the functional property such as a container's bottom that helps contain substance, then generalization was based on the functional property rather than overall similarity.

The view that the theory-based selection of attributes overrides the innate perception selected attributes is consistent with that of Quine's (1977), who argued for both a psychological and a societal progression from an innate similarity-based conception of kinds to a theoretically-oriented basis.

The pre-existing knowledge both enables and constrains the formation of goals by providing a basis for experiencing some new phenomena. Mental models at points

4 and 8 in Fig. 2.4 would provide different bases for domain experience and therefore for forming goals of different levels. Goals, on the other hand, serving as targets, require the new conceptualization to go beyond the conceptual system of the existing mental model, because to be adequate for achieving the goals, the new conceptual system must subsume the new data. As a result, some categories in the pre-existing knowledge may have to be abandoned. Also, it is implied in this framework that lower order knowledge goal-based organization principles will be overridden by higher order knowledge goal-based organization principles. In fact, the model operates in such a way that only the knowledge and goal at the highest cognitive level get to compete for the selection of attributes.

### 2.3.3 The negotiation process

It should be stressed that the preference rule-based process occurs while the cognitive system processes the data. In other words, the three internal variables not only interact among themselves, but at the same time interact with data in both selecting attributes and making membership judgement. This is the moment when constraints on similarity are generated and applied. This is probably why Medin et al. (1993) thought that comparison process is the source of constraints. But as we have seen, behind the comparison process, there is interaction among the three variables, i.e. the innate perception, pre-existing knowledge and goal, which determines how the cognitive system would process the data.

In processing the data, the cognitive system tries to organize the data consistently with the adopted organization principles derived from the preference rule-based interaction. To what extent this consistency can be achieved depends on the constraints, the nature of the data and the negotiation. Most often, the data cannot be completely organized according to the adopted organization principle. In cases where achieving the goal requires subsuming certain data including those not fitting the perspective well, the cognitive system adapts the organization principle or the perspective to the data. But in adapting, it seeks to maximize the consistency with the perspective or principle. The term "negotiation" is used to indicate that when adaptation is necessary, the cognitive system examines the data and assesses the candidate dimensions for their theoretical perspective and implications and the extent to which these dimensions can subsume the data. From this process, the selected dimensions/attributes will overlap across the categories to the extent that the cognitive system adapts the perspective to the data. The more adaptation, the less consistency and the more the attributes overlap across categories. The resulting categories are less projected and less well structured. Because the consistency of attribute selection based on the perspective is compromised, and attributes overlap across categories, membership judgement is not a matter of applying a set all-or-none criteria as in the classic theory. The membership judgement are made with the same constraints with which the attributes are selected. If this is not the case, the attribute selection and membership judgement are not on the same cognitive level. It is equivalent to asking a lay-person to assign a set of objects to scientific categories without him or her having the necessary constraints to make correct membership judgement.

With attributes overlapping across categories and membership judgement based on the same constraints derived from the three variables, objects accepted as category members possess sufficient number of attributes and to a sufficient degree. At the same time, they also possess attributes across categories. Conversely, a non-member object may also have similarities along some of the selected dimensions in a category. But it is judged as a non-member for not possessing enough attributes of the category. This is what we have called the first type of differential attribute sharing, or the family resemblance principle.

A difference is worth noting between categorization in an experimental environment and a natural environment. In the experimental environment, there is usually a set of stimuli for categorization designed in such a way that all the objects or exemplars can be assigned to categories and thus be completely organized, while in the natural world, this rarely happens. Even when the cognitive system adapts to the data, only a portion of the data can be organized. In fact, the cognitive system does not seek to organize all of the data. It needs to organize the data only to a degree adequate for achieving the goal. The rest of the data remains unprojected in the experience field.

To summarize, the categorization process can be seen as a cognitive system with certain conditions negotiating its way through a set of data. To characterize this process, three aspects must be examined: 1) the state of the cognitive system that comes to the categorization process; 2) the nature and source of the data and the relationship between the data and the state of the cognitive system; and 3) the negotiation in data processing. In an effort to explain the state of the cognitive system, we have identified three variables, which represent a broadening of scope to its systemic context for categorization study. We have explained the source of the data and characterized the data in terms of its relations with the categorization process. Finally, the cognitive system adopts organization principles but very often has to adapt to the structure of the data. Most importantly, the knowledge framework puts the categorization process at a particular cognitive level, which is crucial for examining the state of the cognitive system in the categorization process.

# CHAPTER 3

## FEATURES OF CONCEPTS AND THEIR COGNITIVE EFFECTS

In this chapter, we will discuss a number of features generated in the process of the categorization and their cognitive effects. Such features include family resemblance, typicality, distinctiveness, coherence and adequacy. In addition, the implications of elements outside the conceptual field for the categorization process will also be discussed.

### 3.1 The Source of Two Types of Differential Attribute Sharing

In the preceding chapter, the adaptive model mainly concentrates on attribute selection and membership judgement under a set of constraints derived from the interaction of the three variables, i.e. the innate perception, pre-existing knowledge and goal. The chapter also briefly discusses how FR categories are created -- the necessity of adaptation to the data reduces the level of consistency in attribute selection and membership judgement. As a result, category membership cannot be judged by an all-or-none criterion. In other words, attribute sharing is not uniform but differential at two levels: between category members and non-members and among category members themselves.

One component of the proposed knowledge framework (Fig. 2.4) is a three stage process of conceptualization. This component views conceptualization as successive stages of selectively gathering and projecting information so that certain elements of the information form clusters and get organized into an hierarchical system. The multi-cognitive level component puts this process at a particular cognitive level and the adaptive model of category construction attempts to explain why certain information elements are gathered and projected. Through these successive stages, the cognitive system organizes the information by projecting certain elements of information and ignoring other elements. The whole process can be described as trading variety for inference power. It carries a price in terms of relativeness of truth value in the propositions constructed with the concepts.

This can be explained in two ways. Firstly, what we have experienced about reality is not the reality. We do not experience the whole of reality, but only parts or certain aspects of it. The experience of reality is always confined to a particular cognitive level by the pre-existing knowledge. Furthermore, the mind always projects into the reality and actively constructs a mind's version of the reality. One simple example, which Jackendoff (1983) cited from Wertheimen (1912), is called "apparent motion". Two lights flash alternately in a dark surround. Given the proper timing of flashes and not too great a distance between them, the observer experiences "one thing moving back and forth". The motion is supplied by perception.

Secondly, not all information in the experience field can be encapsulated in concepts. The formation of a concept is actually a rather "subjective" process since the process is goal-directed and therefore pragmatic (Holland, et al., 1986). It is constrained by the pre-existing knowledge. The process would leave out all the information it cannot make use of, either because it cannot make sense of the information within the chosen perspective, or because the information is not perceived as relevant to the goal.

Thus a concept is already twice removed from the reality it tries to reflect. It gains order, inferential power and truth value within a certain theoretical perspective and acquires adequacy for a certain set of goals. But in the same process, and by necessity, it ignores a rich variety of potential information. This is the phenomenon of trading variety for inferential power.

The two types of differential attribute sharing occur as manifestations of trading variety for inferential power in the conceptualization stage. In fact, the trading-off takes place also in the experience stage. But the trading-off from the domain reality to the experience field is not directly observable in the formed concepts (see Fig.3.1 on the next page).

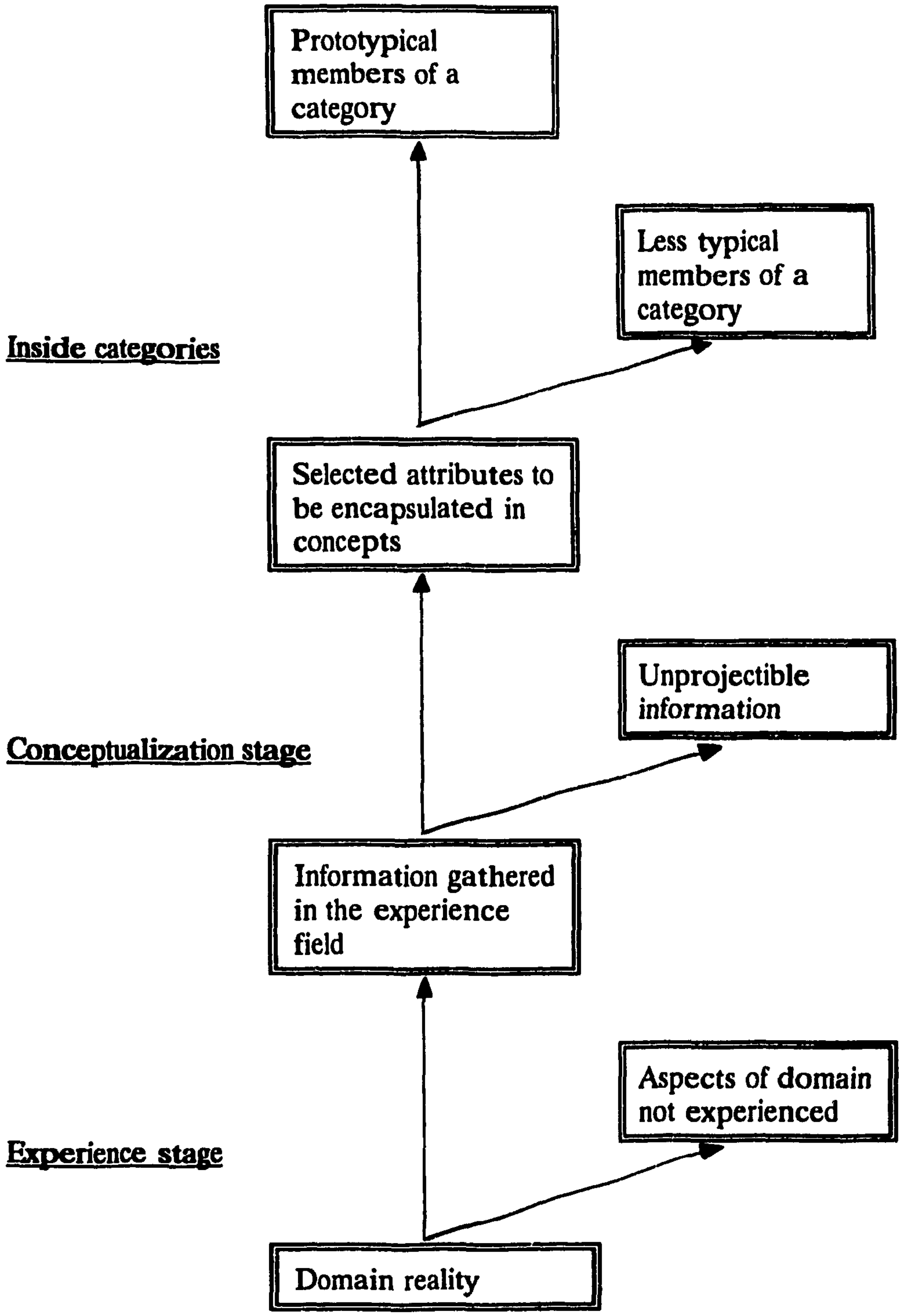


Fig. 3.1 Trading Variety for Inferential Power in All Three Phases

The experience stage has the first trading-off when information is gathered into the experience field. The two types of differential attribute sharing occur at the conceptualization stage. The first type projects certain information into the conceptual field by selecting them as attributes and leaves out other information. This is also where members of concepts are distinguished from non-members (by measuring similarities on the selected attributes). The second type distinguishes more typical from less typical members of the category, giving rise to "typicality".

It is worth noting that people usually take their experience base and their conceptual system at whatever cognitive level it exists as if it were a true reflection of the domain reality, while in fact the truth value of their belief system is relative and limited. Our knowledge framework captures this relative truth nature of any conceptual system and, what is more, is potentially capable of helping to identify it as being at a certain cognitive level.

This account views the projection from the domain reality to the top of the projection where prototypes reside as a continuum. The projection is usually not clean and neat, as it is explained in the adaptive model. In addition, it reveals the intrinsic link between information items inside concepts, those unprojected in the experience field and the unperceived elements outside the experience field. The significance of this is that the information elements in various projection stages are stable at a given cognitive level. But they are not fixed. When we move these information elements across the cognitive levels, they become dynamic. For example, at a lower cognitive level, an information element is unprojected. But at the next higher level, it could be projected as a selected attribute. Indeed, the grain size, identity and integrity of information elements can all change across cognitive levels.

## 3.2 Concept Distinctiveness

In addition to family resemblance and typicality, concepts have other properties such as distinctiveness, coherence and adequacy. Distinctiveness is a property associated with the classical theory. It has survived the criticisms of the classical theory. To better appreciate the distinctiveness property and the subsequently two types of differential sharing, let us briefly review concept distinctiveness in the classical theory.

The classical theory defines a concept by a set of necessary and jointly sufficient features (Bruner, Goodnow, & Austin, 1956; Katz & Postal, 1964). A model typically seen in semantic componential analysis is like the following. A particular semantic field (Lyons, 1977) consists of four concepts, each having three features.

1. H A M
2. H A F
3. H C M
4. H C F

Table 3.1 A Semantic Field Consisting of Four Concepts, Each Having Three Features.

Those with H A M features are members of the category "man", those with H A F features are members of the category "woman", those with H C M features are members of the category "boy" and those with H C F features are members of the category "girl". The superordinate concept of the semantic field is "people", and all the four concepts share the feature H (for HUMAN). The model fits well with the contrastive sets like "man", "woman", "boy" and "girl". The following characteristics of concepts are captured by this model.

1) The relationship among "man", "woman", "boy", and "girl" is one of exclusivity, because of the different/contrastive sets of features encapsulated in the concepts.

2) The relationship between "people" on the one hand and "man", "woman", "boy", and "girl" on the other hand is one of superordinate-subordinate relationship.

3) We have an hierarchical categorization system consisting of "people", "man", "woman", "boy" and "girl".

The significance of these characteristics is this: a concept bundles together a unique set of attributes, and a lexical (or lexicalized) concept institutionalizes a particular set of attributes as one single unit. It thus acquires the status of a distinct entity. Furthermore, a concept exists in a network system. As Rosch (1978) states "... we may conceive of category systems as having both a vertical and horizontal dimension. The vertical dimension concerns the level of inclusiveness of the category - the dimension along which the terms collie, dog, mammal, animal and living thing vary. The horizontal dimension concerns the segmentation of categories at the same level of inclusiveness - the dimension on which dog, cat, car, chair and sofa vary." (p.30) This bundling together of a unique set of attributes to form a concept which exists in a network system with both vertical and horizontal dimensions is concept distinctiveness.

One of the main findings from experimentation using the prototype theory is that concepts are organized according to the family resemblance principle. On one hand, this finding has revealed facts of human categorization, which the classical theory is not able to account for. On the other hand, the family resemblance principle only modifies the distinctiveness of concepts.

Let us see a model which takes account of the family resemblance principle. Instead of proceeding by specifying a set of features of a concept and then saying that objects and events with those features are members of the category, let us suppose we have observed and interacted with some objects in the real world and perceived a string of attributes in each of the objects (See Table 3.2).

| I. | II. | III. |
|---|---|---|
| 1) A B C D | 1) A B O P | 1) A B M N |
| 2) A B F D | 2) D B O P | 2) A C M N |
| 3) G B C H | 3) A E O P | 3) P B M N |

Table 3.2 Attributes in Each Object

Group I has the selected features A B C D; Group II has A B O P; Group III has A B M N. We need to attach values to the features as objects may possess graded features to varying degrees. In the following table, 0 represents absence of a feature and 1 and 2 represent possessing a feature to a low or high degree respectively (See Table 3.3). Note that all the values in this table are values of features of the respective subgroups of Table 3.2.

| I. | A | B | C | D | II. | A | B | O | P | III. | A | B | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1) | 2 | 2 | 2 | 2 | 1) | 2 | 2 | 2 | 2 | 1) | 2 | 2 | 2 | 2 |
| 2) | 1 | 2 | 0 | 2 | 2) | 0 | 2 | 1 | 1 | 2) | 2 | 0 | 1 | 2 |
| 3) | 0 | 2 | 2 | 0 | 3) | 2 | 0 | 1 | 1 | 3) | 0 | 1 | 2 | 2 |

Table 3.3 Graded Attributes Possessed by Each Object

We can form four concepts.

- The nine strings share the attributes A and B to varying degrees (Table 3.2). There is not a common defining attribute. Presumably, A and B overlap in this group of nine strings more than in any other contrasting groups. So we have a superordinate category defined by its strength of family resemblance in A and B. This superordinate category is "S".

- Subgroup I is defined by the overlapping of attributes C and D. D also appears in II.2 and C in III.2 (see Table 3.2). But C and D are shared among the strings in I to a greater degree than the strings in the other two subgroups. Let us name this group of objects "X". Also note that string I.1 is more typical of "X" than I.2 and I.3, since it has more attributes shared to a greater degree among the members of its own subgroup than the other two members.

- Let us call subgroup II "Y", which is defined by O and P.

- We can designate subgroup III as "Z", which is defined by M and N. Note that the subcategories (or the basic-level categories) are generally more clearly delineated than the superordinate category. This is consistent with Rosch and Mervis' finding (1975).

Our adaptive model now conforms to the family resemblance principle. But the property of distinctiveness has survived. We still have a hierarchically organized conceptual field "S", "X", "Y", "Z". The relationship between "S" and the other three is one of superordinate - subordinate relationship. The relationship among "X", "Y", "Z" is still one of incompatibility.

How do we understand the relationship between the family resemblance principle and the distinctiveness of concepts? In brief, a concept must be distinct, or it will not be a concept. The distinctiveness arises not through a set of defining features which objects possess either all or none, but through a differential sharing of the attributes between the inside of the concept and its environment. What the prototype theory has changed is the absolute and equal distinctiveness that the classical theory entails of all members of a category. In other words, prototypical members of a category distinguish the category better from other categories than less typical members, because prototypical members have more attributes shared within the category and fewer attributes shared across categories.

## 3.3 Coherence

Concept coherence is concerned with the meaning aspect of the distinctiveness. It refers to meaning relationships along the vertical dimension and horizontal dimension. Along the vertical dimension, concepts inherit certain attributes such as "animate" in living things, animal, dog, terrier, etc. Along the horizontal dimension, concepts have an incompatible and contrastive relationship.

Concepts also have an issue of coherence among the attributes. Attributes of a concept are not independent but have certain relations with one another. It is generally agreed that attributes of a concept are highly correlated (e.g. Rosch, Mervis, Gray, Jonson & Boyes-Braem, 1976; Smith & Medin, 1981). Murphy and Medin (1985) suggested that the pre-existing knowledge and theories are necessary for people to explain feature correlations. From our point of view, the correlations result from a concept formation process also involving the goal. But more importantly, correlations do not directly indicate what kind of relations exist among the attributes. As far as we know, attributes cluster together to generate an aggregate meaning, that is, the meaning of the concept needed for the cognitive operation on a larger scale where concepts function as units. To achieve the goal of a cognitive operation, all the concepts related in the operation must form a semantically coherent proposition/sentence. For instance, "The boy wants to sleep. Send him to bed." is a coherent cognitive operation and the request can be implemented in action. But "The green idea wants to sleep. Send it to bed." cannot be implemented because concepts of "idea" and "sleep" are not coherent when put in this agent-predicate relationship. In the case of proposition/sentence, the syntactic/logic relation is transparent. In lexical concepts, however, the relations among the attributes are not transparent. The attributes must be coherent for the concept to function in the cognitive operations. In other words, concepts cannot contain attributes which would be considered contradictory or incompatible. For instance, "people" includes both "male" and "female". As "people" are used in gender insensitive contexts, "male" and "female" are not contradictory or incompatible. But "pregnancy" cannot include [MALE], as "pregnancy" has a gender specific function in cognitive operation.

## 3.4 Cognitive Effects of Concept Distinctiveness and Coherence

Concept distinctiveness and coherence make concepts mental constructs capable of entering into rational thinking, for distinctiveness and coherence satisfy three conditions: 1) concepts must have consistent meaning, 2) concept must be unambiguous and 3) concepts must be free of contradiction. These conditions require that concepts have sufficient projection from the experience field. In terms of the family resemblance principle, concepts must maximize the within-category similarity and minimize the between-category similarity, so that concepts can be applied in a certain range of contexts without disintegrating into the context and becoming ambiguous and contradictory. In fact, as we will see in the discussion of concept adequacy (see Section 3.6), concepts are restricted in their application to a range of contexts mainly because they can maintain their distinctiveness and coherence only within the range.

In contrast, information elements not projectible in conceptualization and remaining in the experience field do not enter the abstract reasoning process as distinct units. They are the pragmatic features and are not decontextualized. For example, the colour of the houses is not projected into the categories such as "townhouse", "bungalow", "semi-detached house." When we use these categories in considering what kind of house to buy or rent, it is the structural aspects of the house encapsulated in the categories that are functional. The colour of a specific house is noticed only when we see the house or it is learned in some other way.

Concept distinctiveness and coherence enable concepts to perform the following functions, which are only illustrative, not exhaustive.

-- Concepts are the primary means by which we organize our experience in a particular domain. At any cognitive level, experiences are first organized into concepts before principles, laws and theories can be formulated to represent and explain the external world.

-- Once a concept is formed with experience from a specific environment, it is decontextualized. It can be used to refer to and organize experience with similar attributes in other environments. Because of this characteristic of concepts, humans do not have to recreate concepts each time they encounter a new environment (Mervis & Pani, 1980). Instead, we match the relevant existing conceptual systems with the elements in the new environment, and act on the default assumptions entailed by the existing conceptual systems.

-- Perhaps the most fundamental function of concepts is that they can combine to form new composite concepts (Smith & Osherson, 1984; Medin & Shoben, 1988). Here it is necessary to distinguish simple concepts from composite concepts. The former refers to concepts represented by single lexical items, while the latter is represented by linguistic units larger than lexical items, such as noun phrases (Smith, Osherson, Rips & Keane, 1988). Although we do not know much about how concepts combine, we do know that concepts are the building blocks for larger units of mental representation of the world.

-- Concepts can be used metaphorically (Lakoff & Johnson, 1980). Metaphors are applications of concepts outside their legitimate range of environments. That is, concepts are applied in environments which do not have many of the attributes that the particular concepts have encapsulated. Yet, the application of the concepts brings in some perspectives to otherwise unorganized experience, or new perspectives to an area of experience where stereotypical views stifle creative thinking. Zeman and Boyd (1993) treat metaphorical use of concepts as an evolution process, which destabilizes existing concepts, but may result in new concept production.

The purpose of outlining these functions of concepts in cognitive process is to illustrate that these functions are possible because of concept distinctiveness and coherence. All of this, of course, has to be construed in relative terms. That is, within the appropriate range of cognitive levels, concepts can maintain consistent meaning, free of ambiguity and contradiction.

## 3.5 Cognitive Effects of Typicality

Typicality differentiates attributes by cue validity and members of a category by degrees of typicality (Rosch, Simpson & Miller, 1976; Murphy, 1982). The first implication of typicality in terms of cognitive effects is that semantic functions of concepts are usually better served by more typical members of a conceptual category. Cognitive reference points served by the typical members is one example. More importantly, in an abstract reasoning process, we usually use the more typical side of a conceptual category. Rips (1975), for instance, found that if subjects learn that an unknown property is possessed by a typical species, they are more likely to generalize than if the same fact was learned about an atypical species. While categories have certain range of internal variability, we tend to use the prototypes. The reason is simple: we need maximum distinctiveness and coherence of concepts in abstract thinking in order to keep our thinking "straight".

Effects of prototypes are also found in information memory. We tend to move toward the prototypic value of a category if we can not remember the exact value within the range of the category. Huttenlocher, Hedges and Duncan (1991) presented stimuli at two levels of detail: a fine-grain value within the range of a category and a category prototype. When subjects do not have exact memory but have to report an exact value, they combine the remembered stimulus value with central (prototypic) category value.

However, it is a sign of maturity if one uses conceptual categories with attention to their internal variations. As we have seen, a category is organized around an ideal. However, just as sometimes we have to abandon a category to reconceptualize, we also need to fine tune a category by leaving the ideal and use the category for its less typical and less clearly delineated meaning. In such cases, a category is still useful. Nevertheless, one cannot follow comfortably the "rut" of categories, but has to steer carefully along their edge.

One difference between experts and novices in problem solving performance is in their ability to adapt conceptual categories to problem situations. In trying to make sense of a problem situation with the concepts, a novice struggles to keep the concepts distinct, often rigidly. An expert, on the other hand, looks for fine tuning the concepts to fit the situation, for the real problem situation is rarely captured by the ideal form of a concept. That is, a real situation is often not typical. If a concept can be applied at all, it is probably used for its less distinctive and less coherent variation. Indeed, it is not uncommon that experts partially redefine a conceptual category to better fit a situation.

## 3.6 The Adequacy Rule

Concept distinctiveness and coherence are tied to a particular cognitive level or a range of levels. Concepts maintain their consistency in meaning and freedom from ambiguity and contradiction only at appropriate cognitive levels. In fact, when a concept is applied for its less typical signification, it is already in a fuzzy area where consistency in meaning, freedom of ambiguity and contradiction are hard to maintain. Beyond their range, concepts disintegrate and are simply inadequate for the tasks which require finer distinction and coherent theories at a higher cognitive level. Obvious examples can be found by trying to use the concepts of what is called "folk theories of nature" for scientific research purposes. On the other hand, if we apply concepts that belong to a higher cognitive level to a task at a lower cognitive level, it is a waste of intellectual effort, which Rosch's principle of cognitive economy (Rosch, 1978, p. 28) predicts would therefore not happen often.

Let us look at a simple example. The conceptual categories of "mountain" and "hill" do not have clear boundaries. That is, we do not know when something is not a mountain but a hill. Because of this fuzzy boundary, the application of these two concepts is limited to the environments where the boundary of these concepts is either not questioned (e.g. it refers to close-to-prototype examples and therefore, the contrast is maintained) or irrelevant to the goal of application (i.e. calling something a mountain or a hill does not matter for the purpose at hand). In other words, there are certain environments at a low cognitive level where concepts like "mountain" and "hill" are adequate. However, in the environments where crucial differences reside in the boundary between mountain and hill, the two concepts are not adequate and therefore not used. In these environments, categories of finer differentiation must be used (e.g. above-sea-level height measurements).

A rule for concept application can be formed, which we call the adequacy rule. It says that for a given cognitive task at a given cognitive level, only concepts at that cognitive level are adequate. The rule actually has two parts: 1) concepts from a lower cognitive level are inadequate for tasks at a higher cognitive level and 2) concepts from a higher cognitive level are unnecessary for tasks at a lower cognitive level.

As our framework puts concepts at their appropriate cognitive levels, the adequacy rule can define the extent to which concepts fit the world. A general statement would be: a concept fits the world at its own cognitive level. For example, a concept in the mental model of point 8 in Fig. 2.4 fits the world of the second cognitive level of our framework, for it is adequate for the cognitive tasks at 8-5. Its "correctness" is verifiable at that level of application. A concept does not fit the world precisely if it is stretched toward the edge of its distinctiveness, where the less typical members of the category and non-members are close and often hard to distinguish.

## 3.7 Cognitive Effects of Elements Outside the Conceptual System

Two kinds of elements are outside a conceptual system at any cognitive level:

the unperceived portion of the domain reality outside the experience and the unprojectible information inside the experience field left out by conceptualization. These two elements are at the cognitive frontier where there is chaos but also the rich soil for cognitive growth.

Suppose that "S", "X", "Y" and "Z" that we mentioned in our discussion of Concept Distinctiveness in Section 3.2 are part of a conceptual system of the mental model at point 8 (Fig. 2.4), which has an experience base not beyond point 5. Within this experience base, information elements like E and F in string I.1 (Table 3.2) are not included in the conceptual system at this level. Suppose that at a certain point of time we find the mental model at point 8 inadequate to account for some phenomena of the domain at stage 9-10. This state of finding a mental model inadequate for the domain is largely brought about by the very mental model itself. Typically, there is a time lapse from Time 1 when it was created to Time 2 when it is found inadequate. What happens is that when a mental model is created, cognitive activities in the domain are elevated from the previous cognitive level to a new and higher cognitive level. This elevation enables the cognitive system, in interacting with the domain, to observe more phenomena both in terms of scope and depth. Sooner or later, the previously unknown aspects are experienced and more information is acquired. The experience base expands from point 5 to point 9 (Fig. 2.4). In other words, a new portion of the domain is now brought to the experience base, which requires the cognitive system to categorize the expanded experience base. In the process, the information elements like E and F (Table 3.2) previously excluded from conceptualization may be found to subsume a larger scope of experience and thus selected as attributes of the new concepts. Local changes of this kind eventually destabilize the whole conceptual system and cause the change of the whole mental model of point 8.

To summarize, the family resemblance principle modifies concept distinctiveness by positing that distinctiveness results from differential attribute sharing between inside and outside of concepts rather than all-or-none attribute sharing. Typicality results from the differential attribute sharing inside concepts. Both family resemblance and typicality are explained by the phenomenon called trading variety for inferential power, which, by necessity, occurs in projecting selected information from the experience field to form concepts. Distinctiveness and coherence enable concepts to function as mental constructs in cognitive operations, while typicality reveals the internal variability of concepts which have useful functions: prototypes as reference points in abstract thinking and the less typical for adaptation for problem solving.

The adequacy rule enables us to make a general statement on the extent to which concepts fit the world. It changes the usual statement about concepts being fuzzy and not fitting the world precisely (Lakoff, 1987). The elements outside the conceptual field, namely, the unperceived aspects of the domain and the unprojectible information in the experience field, are both integral parts of the cognitive growth process. It should be noted that we have thus a consistent account of concept formation, starting from the domain experience to the formation of prototypes, and from the source of concept features such as distinctiveness, coherence, typicality and adequacy to their cognitive effects. These features together account for the functions of concepts.

# CHAPTER 4

# EXPERIMENTS

## 4.1 Experiment One

### 4.1.1 Background: The difference between the adaptive model and other models

Of the models we have reviewed in Chapter 1, the *similarity-based models*, tested by simulations, look at the similarity judgement only, without an attempt to explain how similarity is constrained, while Anderson's rational model, also tested by simulations, proposes a criterion for the selection of dimensions, that is, the maximum inference potential. The strength of these models is in the algorithms by which the models can be rigorously tested. The study by Medin et al. (1987) and the two stage model are empirical studies. Medin et al.'s study is based on the similarity model whereas the two-stage model modifies the exemplar sets. Both of them use visual forms with no knowledge depth attributable to them. (For Medin et al. 1987, this is so for the first three experiments.) So neither of them could use pre-existing knowledge to derive constraints for similarity judgement. As a result, they allowed only innate perception in the sorting process.

The adaptive model proposed in this project differs from Anderson's rational model in its account of attribute selection, and from the Medin et al. study and the two stage model in that it focuses on deriving the internal constraints by allowing for use of both pre-existing knowledge and goal in the process. The model was tested by experiments.

The argument is that the cognitive system seeks to organize the data with a consistency not based on innate perception alone as assumed in Medin et al. (1987) and Ahn and Medin (1992). Rather, the cognitive system seeks to organize the data with a consistency that satisfies the constraints derived from the preference rule-based interaction involving the three variables. One may argue that the negotiation process can also be observed when innate perception alone is allowed in the data processing. Indeed, the two-stage model can be viewed exactly in such terms. The cognitive system seeks a consistency by imposing an innate perception based constraint in choosing a dimension and assigning the exemplars to two categories and then by adapting to the leftover exemplars in making overall similarity judgement in the second stage. The point, however, is that the innate perception based constraint is so weak that it takes a delicate arrangement of dimension values to produce overall similarity judgement. In contrast, in our model, the two additional variables (i.e. the pre-existing knowledge and the goal) put the categorization process at the appropriate cognitive level of the knowledge framework and bring in much stronger constraints to the process. For example, the pre-existing knowledge brings with it all the known principles and rules with regard to how the data should and should not be categorized.

### 4.1.2 Method

Ideally an experiment should be conducted in a knowledge rich environment where the adaptive model can be set in a multi-level knowledge framework. However, because of practical constraints, two major simplifications had to be made in testing the model. First, the experiment used artificial stimuli to form artificial categories. Second, innate perception was not used as a variable, but was taken to be a constant in all the conditions.

Hypothesis: FR sorting results from membership judgement based on the constraints derived from the interaction of innate perception, pre-existing knowledge and goal, the same constraints with which the dimension values are selected.

This hypothesis sets our experiment in contrast to those of Medin et. al. (1987) only in one respect, that is, their study allowed for only innate perception in the processing of the data whereas ours allows for the interaction of the three variables. In other words, in Medin et al., when the visual form stimuli were employed with no pre-existing knowledge associated with them, only innate perception or innate standard of similarity could be activated in the sorting process. The constraints thus derived are too weak to generate FR categories with the set of exemplars used, for with the constraints based on innate perception alone, sorting can be done consistently with no need to adapt to the data and consequently no family resemblance structure in the categories could be generated. By contrast, our experiment lets the three variables interact to derive knowledge goal-based constraints for the sorting. Even though the exemplar set used is also visual forms, an artificial knowledge base on the exemplars was created and a goal provided to allow for the interaction to take place.

Medin et al. and Ahn and Medin set their experiments with values across the two categories, not the dimensions. In fact, the two contrasting categories in their experiments have the same dimensions/attributes. To conform to their experiment conditions, the hypothesis in this experiment sets the values of the dimensions overlapping across the categories instead of the dimensions themselves as the condition. So, the within-category similarity as opposed to the between-category similarity is in terms of values rather than dimensions. However, the argument we have made about the constraints should apply here too. Since I want to contrast the adaptive model with their studies, I have formulated the hypothesis accordingly.

Variables: Two independent variables are used: the pre-existing knowledge and the goal. (The innate perception (IP) will appear in all conditions.) Each variable has two conditions. The pre-existing knowledge is operationalized as information on the given dimensions or attributes relevant to the achievement of the goal and the two conditions are: with no information on the attributes (NIN) vs. with information (WIN). The two conditions for the goal are: experimental task demand (ETD) (i.e., with no goal) vs. functional task demand (FTD) (i.e. with goal). The experimental task demand simply requires the participants to assign the exemplars to two categories, whereas the functional task demand sets up a task relevant to the functions of the given attributes. Thus we have 2x2=4 conditions. The dependent variable is the percentage of FR categories created. According to our model, the following predictions are made.

1) IP + NIN + ETD = 1-D (One dimension sorting)
2) IP + WIN + ETD = ?
3) IP + NIN + FTD = ?
4) IP + WIN + FTD = FR

Condition 1 has only the innate perception allowed in processing the data. The condition is the same as that in the first three experiments of Medin et al. (1987). Conditions 2 and 3 each allow an additional variable in the sorting process: Condition 2 the pre-existing knowledge and Condition 3 the goal. Our model does not make specific predictions on these conditions. The guess is that in Condition 2, subjects would have to impose a goal to effectively use the given information on the attributes and produce FR categories. In Condition 3, subjects would have to impute some functions to the features of stimuli to be able to utilize the goal and assign the exemplars to produce FR categories. Condition 4 has innate perception, pre-existing knowledge and the goal in the process of the data. It is this condition that is set up in contrast to Condition 1, and our model predicts that FR categories can only be generated in this condition.

Stimulus material: The material consisted of ten "kangaroo" drawings (see Appendix II). The animals vary in four dimensions, i.e., pouch, body marks, hair and horn, each having two levels or values. The size of pouch varies from small (4mm) to large (10mm), body marks vary from spots to stripes, hair varies from straight to curly, and finally, the length of horn varies from long (10mm) to short (5mm). Two sets of kangaroo drawings are constructed around the two prototypes. The first prototype has long horns, small pouch, spot marks and straight hair. In abstract notation, the values possessed by the first prototype on the four dimensions is 0000. The second prototype has the opposite end of values represented by 1111, and it thus has short horns, large pouch, stripes on the body and curly hair. Each of other exemplars in each set deviates from its prototype on one dimension. Thus we have exactly the same arrangement as that in the first three experiments of Medin et al. (1987).

| | D1 | D2 | D3 | D4 | | D1 | D2 | D3 | D4 |
|---|---|---|---|---|---|---|---|---|---|
| E1 | 1 | 1 | 1 | 1 | E6 | 0 | 0 | 0 | 0 |
| E2 | 1 | 1 | 1 | 0 | E7 | 0 | 0 | 0 | 1 |
| E3 | 1 | 1 | 0 | 1 | E8 | 0 | 0 | 1 | 0 |
| E4 | 1 | 0 | 1 | 1 | E9 | 0 | 1 | 0 | 0 |
| E5 | 0 | 1 | 1 | 1 | E10 | 1 | 0 | 0 | 0 |

Table 4.1 Abstract Notation of Experiment One

In the first treatment condition (C1) (see Appendix III), subjects were presented with this set of exemplars and asked to sort the exemplars into two equal sized categories. As Medin et al. (1987) found and as our model predicts, subjects would use one dimension in categorization instead of judging membership by overall similarity and creating FR categories. According to the two-stage model, the explanation for one dimension sorting is that these exemplars do not even have to pass through the second stage of the model to be classified into two groups because all the exemplars consist of binary values. Whichever dimension is selected as the most salient one, exemplars with characteristic values of a contrasting category on the salient dimension will be grouped with the members of the contrasting category, resulting in 1-D sorting. As the adaptive model attributes the 1-D sorting to weak constraints based on innate perception alone, we do not arrange the values in such a way as to force a second stage. Instead, we bring in stronger constraints provided by the preference rule-based interaction of the three variables.

In the second treatment condition (C2) (see Appendix IV), the same set of exemplars was used. In addition, the information on the functions of the four features was provided. Subjects were required to put the exemplars into two equal sized categories.

In the third treatment condition (C3) (See Appendix V), the same set of exemplars was used as in the first treatment condition. The task demand was changed. Instead of asking the subjects to put the exemplars into two equal sized categories, this condition required the subjects to assign the kangaroos to two groups to accomplish a goal. The information on the functions of the attributes was not provided for the subjects.

The fourth condition (C4) (See Appendix VI) has both information on the features relevant to the task (i.e. the pre-existing knowledge) and the functional task demand (i.e. the goal). The two variables are presented in the following reading passage.

***About the Kangaroos***

*A new species of kangaroo was found on a Pacific island. Scientists have been studying the animal for some time and have made some observations. It was found that the kangaroos had, over the years, gradually adopted two types of habitats on the island: the forest area in the lowland and the prairie in the highland. The conditions of the two habitats are as follows.*

***The forest in the lowland***

1. *It has warm climate year round and very hot summers.*

2. *It has good food sources which are not widely scattered. This means that in the fall kangaroos do not have to travel a wide area to gather and carry food home for the winter.*

3. *It is a relatively dangerous place. There are large animals that prey on kangaroos.*

***The prairie on the highland***

1. *It has cold climate and harsh winters.*

2. *The food sources are widely scattered, which means that in the fall kangaroos must travel widely to gather and carry food home for the winter. As there are not many fruit bearing plants in the area, much of the food source consists of roots of plants, which kangaroos must dig into the sandy soil to retrieve.*

3. *There are very few large animals which are dangerous to the kangaroos in the prairie.*

*Those living in the forest area are called forest dwellers and those living in the prairie are prairie dwellers. It was also found that kangaroos, both male and female, vary in their physical characteristics. Specifically, they vary in four features, i.e., pouch, body marks, hair and horns, as shown in the drawings. The following is known about each of the features.*

1. *Pouch: A kangaroo has either a small or large pouch. Besides carrying babies, in the fall a pouch is also used to carry food gathered from various places to be stored for the winter.*

2. *Body marks: A kangaroo has either spots or stripes on their bodies. Spots provide the animal with a good camouflage, which blends the animal with plant leaves in its surroundings. Stripes provide a good camouflage for the animal in open areas.*

3. *Hair: A kangaroo has either thin straight hair or thick curly hair. Thin and straight hair helps to dissipate the body heat faster. A kangaroo with thick and curly hair has good protection from the elements (e.g. cold weather and rain) and can stay in the open for an extended period of time.*

4. *Horns: A kangaroo has either long horns or short horns. Long horns are better for fighting. Short horns are sturdier and therefore a better tool for digging for food in the ground.*

***Decisions to be made***

*Though the two groups of kangaroos have been evolving apart from each other in adapting to the conditions of their respective environments, they still interbreed. The interbred often share the physical features of both groups to varying degrees. When an interbred young kangaroo leaves its mother's pouch, a decision must be made as to whether the young kangaroo should live in the forest or in the prairie. This is a crucial moment for the young kangaroo because the decision will affect the young kangaroo's chance of survival.*

*Now time has come to make decisions for a group of ten interbred young kangaroos. The young kangaroos are shown on the ten cards. You are to assign five young kangaroos to the forest habitat and five to the prairie habitat. Your goal is to make the assignments in such a way as to ensure the best chance of survival for each kangaroo.*

Thus, by manipulating the variables of pre-existing knowledge and goal, differential cognitive states are created with regard to sorting the stimuli. For instance, participants in C 1 would come to the sorting task with no constraints other than those provided by their innate perception. That is, to these participants, the variation among the kangaroos may have no meaning relevant to the sorting task, apart from the fact that the variation is perceptually obvious. (This is how a similarity model would run the experiments on category construction and predict FR categorization). Participants in C4, on the other hand, would come to the sorting task with a problem to solve (i.e. the goal) which requires the information on the attributes. Thus they would have a set of constraints derived from the knowledge on the attributes and the goal.

#### 4.1.3 Procedures

Ninety-six day-time undergraduate educational psychology students from 4 different classes participated in this study, each class being involved in one of the 4 conditions of the experiment. Intact classes were used. Such an arrangement was employed in an attempt to treat C4 as a single sample test as well as one of the four conditions in a control vs. experimental design and on the belief that the population is fairly homogenous. The mean age of three of the four groups (i.e. C1, C2 and C4) was exactly the same at 23. The mean age of group 3 (i.e. C3) was 25. The tests were all run in a 9:30 a.m. to 12:00 p.m. time slot. In fact, they were all run in the second half of the class.

Participants were told that this was an experiment on categorization and that when the experiment was completed, a short presentation would be given on the specific issues under the investigation and on the design of the experiment. Subjects then received a pack of ten cards (6cm X 9cm) and a booklet. Each card contained the drawing of one of the ten kangaroos to be classified (see Appendix II), and the booklet corresponded to either Appendix III, or IV, or V, or VI, depending on which condition the student was asked to work on. Each kangaroo card is randomly assigned a number from 1 to 10. Participants were asked to spread the cards in front of them as they started to read the instructions in the booklet. In all four conditions, there was a brief introduction to the kangaroos.

Subjects in C1 went straight to the sorting task after reading the introduction. Subjects in C2, C3 and C4 continued reading their assigned passage, subjects in C2 read information on the attributes and their functions (i.e. the pre-existing knowledge), subjects in C3 read the purpose the sorting was to achieve (i.e. the goal) and subjects in C4 read both, as in the passage shown before.

All subjects were asked to sort the kangaroos into two equal sized groups by recording the card number in one of the two tables representing two categories and then to state the reason(s) for assigning the kangaroo to the category. When sorting was completed, the experimenter gave a short presentation on the experiment as promised. When the subjects were asked if they were motivated to work seriously on the task, they all expressed enthusiasm and all said they enjoyed the tasks and took the experiment seriously.

### 4.1.4 Results

The data sorting criterion is as follows. If subjects sorted the kangaroos exactly as shown in Table 4.1, it is FR sorting, for the sorting has maximized the within-group similarity and minimized the between group similarity. If all five kangaroos in a group have the same value on any of the four attributes, it is 1-D sorting, for the sorting is based on one dimension. In cases where sorting is not based on any single dimension, but is not FR sorting either, it is classified as OTHER sorting. Using this criterion, the sorting results are summarized in the following table.

| | C1 | C2 | C3 | C4 | Total |
|---|---|---|---|---|---|
| FR | 0 (0%) | 0 (0%) | 0 (0%) | 21 (78%) | 21 |
| 1-D | 23 (100%) | 18 (75%) | 17 (74%) | 3 (11%) | 61 |
| OTH | 0 (0%) | 6 (25%) | 6 (26%) | 2 (11%) | 14 |
| Total | 23 | 24 | 23 | 26 | 96 |

Table 4.2 Types of Sorting in Each Condition in Experiment One

Chi square was performed to test whether the difference was significant in the proportions of sorting types across the four conditions. As the expected frequency in the four cells for OTH sorting was below 5, 1-D and OTH were collapsed into

NonFR. This was performed according to the recommendation of Siegel and Castellan (1988): "When r is larger than 2 (and thus df > 1), the $X^2$ test may be used if fewer than 20 percent of the cells have an expected frequency of less than 5 and if no cell has an expected frequency of less than 1. If these requirements are not met by the data in the form in which they were originally collected, the researcher should combine adjacent categories to increase the expected frequencies in the various cells. Only after combining categories to meet the above requirement may the tabled significance values for the chi-square distribution be sufficiently close to the actual sampling distribution of $X^2$. ... This may be properly done only if such combining does not rob the data of their meaning." (p. 123) The following contingency table results.

| | C1 | C2 | C3 | C4 | Total |
|---|---|---|---|---|---|
| FR | 0 | 0 | 0 | 21 | 21 |
| NonFR | 23 | 24 | 23 | 5 | 75 |
| Total | 23 | 24 | 23 | 26 | 96 |

Table 4.3 FR and NonFR Sortings in Experiment One

With this contingency table, the test of the overall null hypothesis yields the analysis in the following table on the next page.

| Condition | $f_O$ | $f_E$ | $f_O$-$f_E$ | $(f_O$-$f_E)^2$ | $(f_O$-$f_E)^2/f_E$ |
|---|---|---|---|---|---|
| | | FR | | | |
| C1 | 0 | 5.03 | -5.03 | 25.30 | 5.03 |
| C2 | 0 | 5.25 | -5.25 | 27.56 | 5.25 |
| C3 | 0 | 5.03 | -5.03 | 25.30 | 5.03 |
| C4 | 21 | 5.69 | 15.31 | 234.40 | 41.20 |
| | | NonFR | | | |
| C1 | 23 | 17.97 | 5.03 | 25.30 | 1.41 |
| C2 | 24 | 18.75 | 5.25 | 27.56 | 1.47 |
| C3 | 23 | 17.97 | 5.03 | 25.30 | 1.41 |
| C4 | 5 | 20.31 | -15.31 | 234.40 | 11.54 |
| Total | 96 | 96 | 0 | | $X^2 = 72.34$ |

Table 4.4 Analysis of Experiment One

The test obtains $X^2$ (3, N=96) = 72.34, $p<0.01$. We thus conclude that there is a statistically significant difference in the proportions of FR sorting across the four conditions.

Analytical comparisons were performed between C1 and C4, C2 and C4, and 3 and 4, yielding the analysis in the two tables on the next page. (As Conditions 1 and 3 are the same in their proportions of FR and NonFR, only two tables are needed.)

| Condition | $f_O$ | $f_E$ | $f_O$-$f_E$ | $(f_O-f_E)^2$ | $(f_O-f_E)^2/f_E$* |
|---|---|---|---|---|---|
| | | | FR | | |
| C1 | 0 | 9.86 | -9.86 | 97.23 | 19.33 |
| C4 | 21 | 11.14 | 9.86 | 97.23 | 16.45 |
| | | | NonFR | | |
| C1 | 23 | 13.14 | 9.86 | 97.23 | 5.34 |
| C4 | 5 | 14.86 | -9.86 | 97.23 | 4.55 |
| Total | 49 | 49 | 0 | | $X^2$ = 45.67 |

Table 4.5 Comparison between C1 and C4

*$f_E$ = expected frequency based on the original contingency table (Keppel & Saufley, 1980, p.377).

| Condition | $f_O$ | $f_E$ | $f_O$-$f_E$ | $(f_O-f_E)^2$ | $(f_O-f_E)^2/F_E$* |
|---|---|---|---|---|---|
| | | | FR | | |
| C2 | 0 | 10.08 | -10.08 | 101.61 | 19.35 |
| C4 | 21 | 10.92 | 10.08 | 101.61 | 17.19 |
| | | | NonFR | | |
| C2 | 24 | 13.92 | 10.08 | 101.61 | 5.35 |
| C4 | 5 | 15.08 | -10.08 | 101.61 | 4.75 |
| Total | 50 | 50 | 0 | | $X^2$ = 46.64 |

Table 4.6 Comparison between C2 and C4

*$f_E$ = expected frequency based on the original contingency table. (Keppel & Saufley, 1980, p.377)

The comparison between C1 and C4 gives $X^2$ (1, N=49) = 45.67, p<0.01. The comparison between C2 and C4 gives $X^2$ (1, N=50) = 46.64, p<0.01. The result of comparison between C3 and C4 is the same as that between C1 and C4. We may thus conclude that the differences between C4 and each of the three other conditions are significant.

Finally, Chi square was performed to test the proportion of FR sorting in C4 alone. $X^2$ value with df=1 and N=26 was 9.84, $p < 0.01$.

<u>Protocol analysis</u> In C1 where no pre-existing knowledge or goals were given, of the twenty-three subjects, thirteen sorted by body marks, nine by horns and one by hair. Among them eight subjects stated that their sorting was based on a particular attribute because that attribute seemed most salient or noticeable to them. Three others selected the attribute as basis for sorting by associating the attribute with gender or types of kangaroos. For example, one of them associated the length of horns with the gender of kangaroos, and as no other attributes could be readily associated with a more fundamental classification criterion than that of gender, horn was selected. Two subjects selected body marks by associating the attribute with types of kangaroos. The rest of the subjects simply stated they selected an attribute as basis for sorting.

In C2, information on the attributes was provided, but no goal was given. Of the twenty-four subjects, eighteen produced 1-D sortings and six gave OTHER sorting. Of the 1-D sorting subjects, eight sorted by body marks, five by horns, three by hair and two by pouch. But whether the sorting is 1-D or OTHER, the most noticeable feature in the subjects' reasoning process is that subjects conceived a goal themselves to organize the information given on the attributes. Of the C2 subjects, seven subjects had an explicit goal stated in the verbal description. For instance, one subject, who produced OTHER sorting, wrote: "Kangaroos were either fighters in the open area or more given to caring for the young." Another four subjects associated the functions of attributes with the need they themselves supplied and sorted the kangaroos by fitting the attribute functions to the need, though no goal was explicitly expressed. In fact, OTHER sorting often resulted from associating more than one attribute with the goal supplied by the subjects themselves, while 1-D sorting associated one attribute with the self-supplied goal. One subject grouped the kangaroos according to their ability to survive in the wildness and identified three attributes which are desired qualities in the wildness: long horns, stripes and thin hair. Any kangaroo with 2 of the 3 qualities were grouped together. It is interesting to note that those subjects who did not supply a goal or create a need to relate to the functions of the attributes made no use of the information on the attributes. They ignored the information on the attributes and sorted the kangaroos the way most subjects in C1 did (e.g. by salience of an attribute).

In C3, where the goal was given without the information on the attributes, there were seventeen 1-D sortings and six OTHER sortings. The distribution of the 1-D sorting was: ten by horns, four by body marks, two by hair and one by pouch. Altogether, thirteen subjects speculated on the functions of the attributes in order to relate the attributes to the goal. For instance, horns were seen as an animal's fighting capacity, body marks as camouflage and hair as protection against the elements. Most subjects speculated on the functions of only one or two attributes. If the sorting was based on the association of the goal with the self-supplied function on one attribute, the resulting sorting was one dimensional. If functions on two or more attributes were speculated and used toward goal fulfilment, the resulting sorting was in the OTHER category. The rest of the ten subjects in this condition simply stated that they sorted the kangaroos by a certain dimension without attempting to speculate on the functions of the attributes. They basically ignored the goal provided in the reading passage, for without attribute functions, there was no way to assign the kangaroos in a way which would maximize their chance of survival.

C4 has both the pre-existing knowledge and goal. Subjects readily associated the attributes with the goal through the attribute functions provided. As a result, twenty-one out of all the twenty-six subjects produced FR sorting and only five subjects gave NonFR sorting. One subject actually listed the attributes (i.e. the values of the dimensions) for each of the two groups and then examined each kangaroo to see if it had at least 3 of the 4 attribute values of the category. If it did, it was assigned to the category. If it did not, it must have at least 3 of the 4 attribute values of the contrasting category to be assigned to the contrasting category. This is exactly the kind of overall similarity judgment which maximizes the within-group similarity and minimizes the between-group similarity, a behaviour which is reflected in most of the natural categories known as family resemblance, and which many models of category construction try to reproduce.

### 4.1.5 Discussion

The crucial point that this experiment tests is the assertion that FR categories are the products of a cognitive system coming to the categorization task with a certain perspective, which the cognitive system then adapts to the data in sorting. The perspective is derived from a set of constraints formed with innate perception, pre-existing knowledge and goals.

The results of this experiment support the adaptive model in the following ways.

1) FR sorting was observed only when both the pre-existing knowledge and goal were present. In C4, a significant number of subjects produced FR sorting. In this condition, the pre-existing knowledge and goal formed a set of constraints in the subjects before they came to the sorting. For instance, information on the functions of attributes and the goal of assigning the kangaroos to maximize their chance of survival in the environment would form the constraint that no single attribute alone could be adequate as basis for sorting. In fact, for requisite control variety, all four attributes have to be used. More specifically, constraints such as "thin and straight hair is unfavourable for assigning a kangaroo to the prairie group" can also be derived. Even when the goal is removed, the very information that "the body marks have the function of camouflage" would serve to orient subjects' attention with regard to the attribute. Such constraints enable subjects to derive a perspective with regard to how to group the kangaroos. Subjects formed two prototypes, a typical forest kangaroo and typical prairie kangaroo. However, when subjects came to the sorting, they found most kangaroos did not fit perfectly into the ideal, for except E1 and E6, each deviates from the prototype along one dimension. Subjects must adapt the perspective to accommodate the data. But in adapting, subjects sought to maximize the consistency with the perspective and decide that if a kangaroo possessed three of the four attribute values of the group, it should be assigned to the group, thus

resulting in FR sorting.

2) When either the pre-existing knowledge or goal is missing, no FR sorting was observed. Subjects in C2 and C3 had either information on the attributes or goal but not both. It is important to note that about half of the subjects in both conditions supplied the goal or speculated on the functions of the attributes. However, none produced FR sorting. This can be explained in the following way. First, in the case of C2, subjects who created a goal or need, often with functions of one or two attributes in mind, sorted the kangaroos based on that one or two attributes, resulting in 1-D or OTHER sorting, whereas in this experiment, the goal was designed to implicate all four attributes with the aim to maximize the within-group similarity. It is unlikely that any self-supplied goal would involve this complete implication. Similarly, in C3, subjects mostly speculated on the functions of only one or two attributes and, therefore, were not likely to optimally assign the kangaroos as the goal required. However, the fact that many subjects created a goal or speculated on the functions of attributes supports the thesis that both the pre-existing knowledge and goal are the variables playing important roles in categorization.

3) C1 replicated the experiments of Medin et al. in 1987. The gross result is the same as that of their study, namely, no FR sorting was observed, although according to the similarity-based model, FR sorting should result. The adaptive model explains the absence of FR sorting by pointing to the lack of sufficient constraints from within the cognitive system doing the sorting. That is, the constraints subjects derive from visual perception of the stimuli are not sufficient. The innate perception

based constraints lead subjects to look for consistency in sorting along a perceptually salient dimension. When this consistency can be found (e.g. five long horns and five short horns), there is no reason for subjects to look further for other attributes to make overall similarity judgment in order to maximize the within-group similarity and minimize the between group similarity. The needed stronger constraints could only come from the pre-existing knowledge and the goal in C4.

## 4.2 Experiment Two

### 4.2.1 Rationale

Experiment Two was motivated by two considerations. First, the adaptive model of category construction argues that FR categories are created when the cognitive system adapts to the data in both attributes selection and membership judgement. While Experiment One looked at the effects of the pre-existing knowledge and goal on membership judgement using the pre-selected dimensions, Experiment Two would investigate the effects of the pre-existing knowledge and goal in both selection of dimensions/attributes and membership judgement.

The second consideration was to test the internally generated constraints with a set of exemplars, which the two-stage model predicts would not generate FR categories. As was described in Chapter 2, the two-stage model (Ahn & Medin, 1992) holds that "... people tend to create categories with defining features and if the strategy does not work for some exceptional examples, they tend to patch them up by adding description for the leftover examples." (p. 88) In other words, people first select a primary basis for sorting exemplars, and when faced with some leftover exemplars which do not fit the primary criterion, people are forced to make an overall similarity judgment over other dimensions, thus producing FR categories. To make subjects go through the second stage of sorting to produce FR categories, the two-stage model has to impose a condition on the exemplar set. That is, categories created on the FR principle must have a sufficient number of features that do not appear in potential contrasting categories. In other words, the extreme attribute values of the contrasting categories must not overlap across the categories. Only an intermediate value is allowed to overlap. To illustrate more specifically how the two stage model works, let us see an example set and work through it (see Table 4.7).

| | D1 | D2 | D3 | D4 | | D1 | D2 | D3 | D4 |
|---|---|---|---|---|---|---|---|---|---|
| E1 | 0 | 0 | 0 | 0 | E6 | 2 | 2 | 2 | 2 |
| E2 | 0 | 0 | 0 | 1 | E7 | 2 | 2 | 2 | 1 |
| E3 | 0 | 0 | 1 | 0 | E8 | 2 | 2 | 1 | 2 |
| E4 | 0 | 1 | 0 | 0 | E9 | 2 | 1 | 2 | 2 |
| E5 | 1 | 0 | 0 | 0 | E10 | 1 | 2 | 2 | 2 |

Table 4.7 Abstract Notation of Stimulus Set A Used in Ahn and Medin (1992)

In Table 4.7, if we use D1 as the most salient dimension, E5 does not have value 2 and E10 value 0 to put them in their respective contrasting groups. Instead, in the first stage, E1, E2, E3 and E4 are classified as one category and E6, E7, E8 and E9 are classified as another. "In the second stage, because E5 is more similar to E1, E2, E3 and E4 than to E6, E7, E8 and E9, it is categorized with E1, E2, E3 and E4. Similarly, E10 is categorized with E6, E7, E8, and E9. Therefore, as a result of second stage, the model generates FR categories for this set." (p.90) Here 0 and 2 are extreme values not allowed to appear in the contrasting category. In case they were to overlap across the two categories, then E5 would share the same attribute value of 2 on the first dimension with E6, E7, E8 and E9, and E10 with E1, E2, E3, and E4, resulting in 1-D sorting with the two assigned to their respective contrasting categories. This is exactly how the two-stage model explains the 1-D sorting results of Medin et al. (1987).

In Ahn and Medin (1992), four sets of exemplars were developed (see Table 4.8).

| Set A | | Set B | |
|---|---|---|---|
| E1 0000 | E6 2222 | E1 0000 | E6 2222 |
| E2 0001 | E7 2221 | E2 0001 | E7 2220 |
| E3 0010 | E8 2212 | E3 0020 | E8 2212 |
| E4 0100 | E9 2122 | E4 0100 | E9 2022 |
| E5 1000 | E10 1222 | E5 2000 | E10 1222 |

| Set C | | Set D | |
|---|---|---|---|
| E1 0010 | E6 1221 | E1 0010 | E6 1221 |
| E2 0011 | E7 2212 | E2 0031 | E7 2242 |
| E3 0100 | E8 2211 | E3 0100 | E8 2214 |
| E4 1100 | E9 2122 | E4 1300 | E9 2422 |
| E5 1001 | E10 1122 | E5 3003 | E10 4122 |

Table 4.8 Abstract Notation of Sets A, B, C, and D from Ahn and Medin (1992)

Sets A and D have more between-category difference than Sets B and C, and Sets A and B have more within-category similarity than Sets C and D. One of the major predictions the two-stage model makes is that whether FR sorting will be produced depends on the degree of overall similarity of the remaining exemplars to the initially created categories. Set C has less within-category similarity than Set B, but it has sufficient features in the resulting FR categories. The general prediction is that Sets A, C, and D would generate FR categories and that Set B would not, because Sets A, C, and D have sufficient features that do not appear in the potential contrasting categories whereas Set B has extreme values 0 and 2 crossing into contrasting categories in E3, E5, E7 and E9.

The two-stage model thus manipulates the exemplar sets to create external constraints, namely, by allowing only the intermediate values to overlap the two categories. The model creates a situation in which subjects, confronting the intermediate value, cannot simply assign the exemplar to either category, thus forcing subjects to look at other dimensions for similarity judgment.

By contrast, the adaptive model does not depend on the manipulation of exemplar sets. It creates internal constraints in the cognitive system through the pre-existing knowledge and goal. In Experiment Two, an exemplar set with extreme values overlapping across the two contrasting categories was used. It is predicted that FR categories can be generated with this exemplar set in the adaptive model, thus demonstrating that the adaptive model is more robust in generating FR categories than the two-stage model.

### 4.2.2 Method

Hypothesis FR categories are created with an exemplar set with not only intermediate but also extreme values overlapping across the potential contrasting categories, if and only if both selection of dimensions/attributes and membership judgement are made with the constraints derived from the interaction of innate perception, pre-existing knowledge and goal at an appropriate cognitive level.

Two treatment conditions corresponding to C1 and C4 of Experiment One were set up for Experiment Two. That is, in C1 of Experiment Two, only innate perception is available for processing the data. In C2 of Experiment Two, pre-existing knowledge and the goal are also made available in addition to the innate perception. Of the six attributes used in Experiment Two, four are relevant to the defined goal. Hence there is now an attribute selection aspect in categorization. The predictions are that C1 would generate 1-D sorting and that only C2 would generate FR sorting.

Variables In this experiment, the pre-existing knowledge and goal were treated as one variable, since Experiment One showed that if either the pre-existing knowledge or goal appears without the other in categorization, subjects either infer and supply the other or disregard the information of the variable given. The dependent variable is still the percentage of FR categories generated. The point is that constraints derived from the interaction of the innate perception, pre-existing knowledge and goal will guide the selection of the relevant attributes, attribute values and the membership judgement. The constraints are such that the selected exemplars accepted as members of a category possess attribute values across categories, resulting in FR categories.

Stimulus material Instead of four attributes shown in the drawings in Experiment One, six attributes were used in this set (see Appendix VII). The attributes were pouch, stripes, hair, horns, upper-body spots and neck-rings.

Moreover, each attribute had three values from 1 to 3. Pouch varied from large (10mm) to small (5mm) and to no pouch. The number of stripes varied from two to one and to no stripe. Hair varied from thick and curly to thin and straight to no hair. Horns varied from long (10mm) to short (5mm) and to no horn. The number of upperbody spots varied from two to one and to no spot. Finally, the number of neck-rings varied from two to one and to no neck-ring. The prototype of group one (i.e. E1) has values of 1 for all six dimensions, thus the values 111111 stand for no pouch, two stripes, no hair, long horns, no upperbody spot and no neck ring. The prototype of the second group (i.e. E8) has values of 3 for all six dimensions, thus the values 333333 stand for large pouch, no stripe, long hair, no horns, two upperbody spots and two neck rings. Value 2 is intermediate between the two extreme values of 1 and 3, thus it stands for small pouch, one stripe, straight hair, short horns, one upperbody spot, and one neck ring. The abstract notation of the exemplar set is shown in Tables 4.9 and 4.10.

| | Horns | Stripes | Hair | Pouch | Rings | Spots |
|---|---|---|---|---|---|---|
| E1 | 1 | 1 | 1 | 1 | 1 | 1 |
| E2 | 1 | 1 | 1 | 1 | 2 | 2 |
| E3 | 1 | 1 | 1 | 2 | 1 | 3 |
| E4 | 1 | 1 | 2 | 1 | 3 | 1 |
| E5 | 1 | 2 | 1 | 3 | 1 | 1 |
| E6 | 2 | 1 | 3 | 1 | 1 | 1 |
| E7 | 2 | 3 | 1 | 1 | 1 | 1 |

Table 4.9 Abstract Notation for Group One

| | Pouch | Hair | Stripes | Horns | Rings | Spots |
|---|---|---|---|---|---|---|
| E8 | 3 | 3 | 3 | 3 | 3 | 3 |
| E9 | 3 | 3 | 3 | 3 | 2 | 2 |
| E10 | 3 | 3 | 3 | 2 | 3 | 1 |
| E11 | 3 | 3 | 2 | 3 | 1 | 3 |
| E12 | 3 | 2 | 3 | 1 | 3 | 3 |
| E13 | 2 | 3 | 1 | 3 | 3 | 3 |
| E14 | 2 | 1 | 3 | 3 | 3 | 3 |

Table 4.10 Abstract Notation for Group Two

A number of points should be noted here. First of all, the stimulus set perfectly meets the requirement of the similarity model, namely, that exemplars in each group share more attribute values within the group than across the groups. So if the view is true that FR categories are formed by abstracting central tendency through overall similarity judgment, a process which would maximize the within-group similarity as opposed to the between-group similarity, then this set of stimuli should generate FR categories.

Second, this set of exemplars has the extreme values of all dimensions except one for each group crossing the categories. Therefore, according to the two-stage model, this set of stimuli would not produce FR categories.

Third, it might be noticed that the attributes in the two groups are arranged differently. In group one, the first two attributes are "horns" and "stripes" while in the second group, the first two attributes are "pouch" and "hair". This arrangement is made to give each group a core attribute, which does not share the extreme value of the contrasting category. Thus in group one, attribute "horns" does not have the extreme value, i.e., "no horns" of the contrasting category. Similarly, in the second group, "pouch" does not have the extreme value, i.e., "no pouch" of the contrasting category.

For the second condition, the following reading passage was developed to provide pre-existing knowledge and goal for the sorting task.

***What is known about the kangaroos***

*A new species of kangaroo was found on a Pacific island. Scientists have been studying the animal for some time and have made some observations. It was found that kangaroos live in groups. In each group, adult kangaroos, both male and female, are always found to vary in the six features as shown in the drawings. The following is known about each of the features.*

1. *Pouch:*
   *Kangaroos vary by having no pouch, a small pouch or a large pouch. A pouch is useful (in addition to carrying babies in the spring) for carrying food gathered from various places in the fall to be stored for the winter.*

2. *Stripes:*
   *Stripes indicate a kangaroo's rate of metabolism, which affects the temperament of the animal. It is found that the more stripes a kangaroo has, the more it becomes irritable and aggressive. When a kangaroo has no stripe, it is very active, energetic and hard working.*

3. *Hair:*
   *A kangaroo sheds its hair every third summer. In the following fall, it grows thin and straight hair. The hair will grow thick and curly a year later.*
   *A kangaroo without enough hair may get sick if exposed to cold and harsh weather. A kangaroo with thick and curly hair has good protection from the weather and can stay in the open for an extended period of time.*

4. *Horns:*
   *A kangaroo sheds its horns three times in a life time. When a kangaroo sheds the horns, it has no horns. It takes about a year for the animal to grow short horns, which will grow to the full length in two years. Horns are the most important weapon. The longer the horns, the more advantage a kangaroo has in fighting.*

5. *Upper body spots:*

*A kangaroo group is usually composed of several families. The number of spots indicate family lineage of the kangaroos. That is, kangaroos with the same number of upper body spots are from the same family.*

6. *Neck-rings:*
   *The rings on the neck indicate the patterns of courting behaviour. The more rings, the more active a kangaroo is in courting and looking for mates. However, at the present, very little is known about other social behaviour of the kangaroos.*

***What the kangaroos must do in the fall***

*There are no predators on the island. Animals do not kill for food. However, survival is a constant struggle on the island because of the scarcity of food. Kangaroos get into a fight only when defending their stored food.*

*The food source is widely scattered. As they cannot find large quantities of food in any one place, kangaroos travel around the island in the spring and summer. However, in the fall, a kangaroo group must settle down and build a den in which to store food for the winter. Thus in the fall, all adult kangaroos are engaged in two tasks: to travel and gather food and to guard the stored food. Those who travel to look for food are gatherers and those who stay behind and guard the stored food are guards. As kangaroos vary in their temperamental fitness, carrying capacity and protective ability from cold and rain, some are better suited for the task of gatherers than others. As they also vary in their ability to fight and guard the stored food, some are better suited for the task of guards than others.*

*The environmental conditions on the island are such that the survival of the group depends on an optimal assignment of the kangaroos to the two tasks. That is, optimal assignment helps them avoid either being unable to gather enough food for the winter or being unable to protect the stored food.*

*Here we have a typical group of 14 kangaroos which are shown on the cards. Time has come for assigning the kangaroos to the two task groups. We are interested in how you would assign the kangaroos to be gatherers and guards in such a way as to ensure the group the best chance to survive the winter.*

With the pre-existing knowledge and goal present in one condition and absent in the other, differential cognitive states were created. That is, subjects in C1 had no other constraints than what their innate perception could impose while subjects in C2 came to the sorting task with a goal to achieve and with information on the functions of attributes necessary for achieving the goal. Thus the subjects in C2 had a set of constraints quite different from those in C1.

### 4.2.3 Procedures

Thirty-two undergraduate educational psychology students participated in this study. The subjects were randomly assigned into two groups, according to the odd or even number they picked. The two conditions were run in separate rooms on the same floor. An assistant was hired to help the experimenter implement the procedures.

As in Experiment One, subjects were told that this was an experiment on categorization. But as the experiment was conducted in the evening and subjects stayed beyond the regular class time after nine o'clock, no presentation was made on the experiment. Instead, the experimenter prepared handouts to be given to the participants after the experiment was run. The handout explained the issue under investigation and the design of the experiment.

Each subject received a pack of 14 cards (5cm x 8cm) (Appendix VII), each containing the drawing of a kangaroo, and a booklet. Subjects were asked to spread out the cards before them as they read the instructions in the booklet (see Appendix VIII for C1 and Appendix IX for C2). In both conditions, as in Experiment One, there was a short introduction to the kangaroos. Subjects were asked to take a careful look at the values of the kangaroos' six features, i.e., pouch, stripes, hair, horns, upper body spots, and neck-rings.

Following the introduction, subjects in C1 went straight to the sorting task. They were instructed to sort the 14 kangaroos into two equal sized groups by recording the card number at the back of the card in the left column of the two tables labelled GROUP ONE and GROUP TWO respectively. After assigning a kangaroo to one of the two groups, subjects were required to give reason(s) for making the assignment.

Subjects in C2 read the passage on the functions of the attributes and on the goal before going to the sorting task. They were instructed to sort the kangaroos into Gatherers and Guards by putting the number at the back of the cards into the leftmost column of two labels labelled Gatherers and Guards. Subjects were requested to give reason(s) for assigning each kangaroos to either group.

### 4.2.4 Results

The criterion for classifying the sortings was a little more complicated than that of Experiment One. As only six instead of seven kangaroos could have the same value on any single dimension, any sorting which had six kangaroos possessing the same value on a dimension was classified as 1-D sorting. FR sorting is as shown in Tables 4.11 and 4.12. If subjects produced sortings which did not have six kangaroos in one group possessing the same value on a dimension and were not FR sorting either, they were classified as OTHER sorting. The sortings are summarized in the following table.

| | C1 | C2 | Total |
|---|---|---|---|
| FR | 0 (0%) | 6 (38%) | 6 (19%) |
| 1-D | 10 (62%) | 9 (56%) | 19 (59%) |
| OTH | 6 (38%) | 1 ( 6%) | 7 (22%) |
| Total | 16 | 16 | 32 |

Table 4.11 Types of Sorting in Two Conditions in Experiment Two

Fisher's exact test was performed, as the expected frequency in two cells was below 5. To construct a 2x2 contingency table for Fisher's exact test, 1-D and OTHER sortings were collapsed to form the NonFR sorting category. The resulting contingency table is as shown on the next page.

| | C1 | C2 | Total |
|---|---|---|---|
| FR | 0 | 6 | 6 |
| NonFR | 16 | 10 | 26 |
| Total | 16 | 16 | 32 |

Table 4.12 FR and NonFR Sortings in Experiment Two

Fisher's exact test uses the following formula to calculate the probability that the observed difference in proportions between the two conditions is due to chance.

$$P = (A+B)!\ (C+D)!\ (A+C)!\ (B+D)!\ /\ N!\ A!\ B!\ C!\ D!$$

This formula, applied to our contingency table, gives

$$P = 6!\ 26!\ 16!\ 16!\ /\ 32!\ 6!\ 0!\ 10!\ 16!$$

$$P = .009$$

As there is a 0 in one of the cells, no recursive computation is needed (Siegel & Castellan, 1988, pp. 102-111). Thus we may conclude that there is a statistically significant difference in proportions of FR sorting between the two conditions.

Protocol analysis In C1, of the ten 1-D sortings, five subjects made sortings based on horns (e.g. 6 long horns plus 1 short horns), two others on hair, still two others on spots and one on stripes. Of the six OTHER sortings, two subjects sorted randomly, two sorted according to the number of features (i.e., kangaroos with fewer observable features are grouped together and those with more observable features are grouped together), one subject did sorting based on two dimensions, and the last subject's criterion for sorting was not clear. Two subjects explained that they at first tried to sort according to a certain dimension, but none leads to the neat sorting of two groups of seven members. No subject indicated an attempt to make an overall similarity judgment which would lead to FR sorting.

In C2, the protocols of 6 FR sortings were closely examined. They all in fact shared the following points. 1) The subjects all formed the prototypes of the two categories by listing a set of desired characteristics for gatherers and guards. 2) The subjects did not presume anything nor misunderstand the reading passage providing information on the attributes and goal. 3) The subjects all managed to weigh and balance the attribute values in assigning kangaroos which possess attributes values of both categories to a confusable point. For example, E5 has long horns, a core feature of guards, and a large pouch, a core feature of gatherers. By these two features alone, it would be difficult for one to make an assignment. However, E5 also has one stripe, also a guard's feature. On balance, that one stripe should favour assigning E5 to Guard group instead of Gatherer group, even though E5 only possesses the stripe to a moderate degree.

Note that it is this kind of inferential reasoning that makes one examine all the functional attributes in sorting (i.e. overall similarity judgment) and the facilitation behind this reasoning is a set of constraints derived from the goal and knowledge of the functional attributes. One subject, for instance, gave his reasoning in assigning N0. 11 and N0. 5, which correspond to E7 and E14 respectively: "Number 11 didn't have any strength but he was assigned to guard duty due to his lack of pouch and (possession of) medium horns. Number 5 was assigned to gatherer duty due to lack of horns and stripes and (possession of) medium pouch."

Nine subjects in C2 produced 1-D sorting. Their protocols indicated that five of them formed prototypes of the two categories. For example, one subject wrote: "The kangaroos who had large pouches, curly hair with no stripes, small horns were best suited for the gatherers. The kangaroos who had large horns, more stripes, small pouches were best suited for the guards." However, these subjects all produced 1-D sorting.

The 1-D sorting result may be explained in two ways. One is that five of these subjects formed prototypes. In other words, they had derived necessary constraints from the reading passage when coming to the sorting task. But in assigning the kangaroos, they failed to weigh and balance a number of highly confusable kangaroos, in particular, E5, E14 and E13. All of these five subjects put E5 in the gatherer group, picking up its feature of large pouch while neglecting the fact that it also has long horns and one stripe, which should outweigh the large pouch feature. They substituted E5 with either E13 or E14 to the guard group. E13 had two stripes, which was a strong guard's feature. But it also had curly hair and a small pouch, which should outweigh the feature of two stripes in favour of assigning it to the gatherer group. As a result of switching E5 with either E13 or E14, these subjects did not manage to make optimal assignments to ensure the maximum performance of the kangaroos as required in the goal.

It thus can be argued that the 1-D sortings produced by these five subjects in C2 differ from those produced by the subjects of C1 in that while the 1-D sortings in C1 resulted from the lack of sufficient constraints, the five 1-D sortings in C2 resulted from failure to observe the constraints.

Some subjects produced 1-D sortings either by presuming things not given in the reading passage or by misunderstanding the reading passage. One subject, for instance, purposely assigned kangaroos with no pouches but with horns to the gatherer group. "My reason is that the rest of the gatherers need some type of body guards because some do not have horns to protect themselves against enemies." This happened despite the warning against presuming things in the reading passage. As a result, these subjects did not derive the needed constraints for the sorting task. They derived their own set of constraints.

It is noted that in C2, two attributes, spots and neck rings, are actually not relevant to the goal and no subjects made the two attributes functional in sorting. Two subjects mentioned them while basing their sorting on other attributes. One subject specifically pointed out that these two attributes are irrelevant to the task. In contrast, we may observe that in C1, two subjects made their sorting based on spots and nine subjects mentioned the two attributes in their sortings.

### 4.2.5 Discussion

Let us first take a look at the results of Experiment One by Ahn and Medin

(1992), where subjects were asked to create two categories of any size (see Table 4.13).

| | Set A (%) | Set B (%) | Set C (%) | Set D (%) |
|---|---|---|---|---|
| FR | 55 | 0 | 35 | 20 |
| 1-D | 45 | 100 | 10 | 65 |
| Others | 0 | 0 | 55 | 15 |

Table 4.13 Types of Sorting in Each Set in Experiment One from Ahn & Medin (1992).

The difference between Sets C and B in the proportions of FR sorting was found to be significant. The difference between Sets D and B was marginally significant, P=.053. Thus the two-stage model was supported.

But here we can point out at least one important weakness in the two-stage model. Having sufficient features that do not appear in the contrasting categories is one thing and allowing no extreme values of any attributes to cross to contrasting category is quite another. Categories can have sufficient features shared by their members only, and yet still have extreme values of some attributes overlapping contrasting categories. The two-stage model in fact allows only an intermediate value to cross the categories. An exemplar set with any extreme values crossing to the contrasting categories immediately eliminates the second stage, resulting in 1-D sorting. This obviously does not correspond to what we can observe in natural categories with family resemblance characteristics. In fact, the very notion of family resemblance structure denotes the overlapping of attributes, including the extreme values of certain attributes, across categories. Categories need sufficient projection to maintain the contrastiveness. But this does not mean no extreme values should cross into contrasting categories. In other words, the two-stage model can not handle an exemplar set which has extreme values crossing into contrasting categories, but where the potential categories still have a sufficient number of features shared within the categories to attain their integrity. If the two-stage model cannot handle this kind of exemplar set, it is not robust enough to match the robustness of natural FR categories.

Such an analysis of the two-stage model is intended to provide a context for discussing of the results of Experiment Two. The crucial difference between the adaptive model and the two-stage model lies in the way constraints are provided. The former mainly uses internally generated constraints while the later mainly uses the constraints from the exemplar set, hence leading to the difference in the cognitive process in categorization. With the two-stage model, the cognitive system picks up a salient dimension as the basis for the first stage sorting, which is unidimensional. By contrast, with the adaptive model, the cognitive system forms an ideal or prototype with the pre-existing knowledge and goal, which involves the integration of the component attributes.

In C2 of Experiment Two, subjects would conceive an ideal gatherer and guard by considering all the goal-relevant attributes, namely, the gatherer should have a large pouch, curly hair, and no stripe, etc., and the guard should have long horns and two stripes. In other words, this process is not unidimensional from the very first stage of sorting.

Both models have a second stage. The two-stage model deals with the leftover exemplars by relying on the intermediate value of the primary dimension to create an impasse, thus forcing subjects to look at similarity along other dimensions. (This is why if an extreme value crosses to the contrastive category, and the attribute happens to be picked as the primary basis, no such impasse can be created and the second stage is eliminated.) By contrast, with the adaptive model, when subjects encounter the exemplars that do not fit the ideals well, they adapt the ideal to the these exemplars. That is, they compromise the ideal in order to accommodate the exemplars. But in doing so, subjects still make a similarity judgment between the exemplars and the ideal. As the ideal is integrated from the component attributes, the similarity judgment is an overall similarity judgment across all relevant attributes. In Experiment Two, E5 and E13 are such leftovers. E5 has a large pouch, long horns and one stripe. It does not fit well to either ideal gatherer or guard. However, it is compared with the two ideals and it is closer to guard by its possession of one stripe.

# CHAPTER 5

## GENERAL DISCUSSION AND IMPLICATIONS

### 5.1 General Discussion

One may ask why Medin and his co-workers did not use pre-existing knowledge and goal as two variables to constrain similarity, although he argued for the role of pre-existing knowledge in attribute selection (Murphy & Medin, 1985; Medin, 1989) and consistently searched for ways to constrain similarity (Medin et al., 1993). This question is fair, only if one asks it with a view to reviewing the background research trend in the area and allows for personal interpretation of the situation.

Medin and his co-workers are among the first to argue for the inclusion of pre-existing knowledge in deriving constraints for similarity judgement. Murphy and Medin outlined five roles of theories in conceptual coherence (Murphy & Medin, 1985). Medin et al. (1993) attribute the difference between children and adults in their response to "cloud" and "sponge" comparison to the difference in their pre-existing knowledge. In fact, Medin et al. (1987) moved in the direction of using pre-existing knowledge. In their experiments 5 to 8, correlated attributes (e.g. dizziness and earache) were used to create "integration across component dimensions". That is, there are interproperty relationships in natural categories, in which simple matching and mismatching of properties would not be sufficient to capture.

"Correlated attributes" and "integration across component dimensions" patently speak of pre-existing knowledge, for only where pre-existing knowledge is employed, can there be interproperty relationships and cross component integration. Medin et al. (1987) conclude: "Family resemblance categories may be organized not so much in terms of their surface features or properties but in terms of a deeper underlying concept that may give rise to them" (p. 273). In other words, the observed family resemblance in natural categories may have underlying knowledge behind them and therefore family resemblance cannot be recreated by superficially matching and mismatching features.

However, for some reason, Medin and his colleagues did not follow this direction of research. In Ahn and Medin (1992), which was taken from the first author's doctoral thesis, the two stage model was proposed, which, as we have seen, gave no consideration to pre-existing knowledge. Instead, it returned to the matching and mismatching features, only with an additional externally imposed constraint. That is, by using intermediate values across potentially contrasting categories, the experiment forced the subjects to consider other dimensions.

One of the major difficulties in employing pre-existing knowledge for deriving constraints on similarity lies in the difficulty of stratifying the pre-existing knowledge and identifying knowledge at an appropriate cognitive level. As is stated in Chapter 2, as soon as we come to the point of attribute selection, we must come to grips with cognitive levels, for constraints on similarity judgement are largely derived from the mental model at the highest available cognitive level in the domain. The preference rule-based interaction component of the adaptive model is designed to allow the mental model at the highest cognitive level to override not only the innate standard of similarity (i.e. the constraints derived from the innate perception) but all the constraints from the mental models at lower cognitive levels. People with mental models at different cognitive levels perceive different phenomena in the same domain and even when they do look at the same objects, they select different sets of attributes for similarity comparison. In other words, because they use mental models at different cognitive levels, the constraints people employ in attribute selection are different. Therefore, developing a coherent account for the cognitive levels becomes a prerequisite for explaining how appropriate constraints are derived for similarity.

With the framework of knowledge development, we are able to account for the progression from the innate standard of similarity to theory-based similarity standard at an appropriate cognitive level. In other words, the framework exhibits what it is to have a cognitive system which has attained the domain knowledge to an appropriate level for the categorization task. For example, the particular level of domain knowledge, at point 8 of our framework (Fig. 2.4), accounts for the expanded experience field from point 5 to point 9 (for, as was said before, the acquisition of experience at point 9 requires the domain knowledge at point 8), which in turn, accounts for the goal derived from the need to understand the observed phenomena. Thus in this account, the data, pre-existing knowledge and goal are interrelated and integrated. More importantly, the framework provides a basis for deriving the set of constraints for selecting attributes along which similarity was compared.

The adaptive model of categorization operates at a specific cognitive level and accounts for the rule-based interaction among innate perception, pre-existing knowledge and the goal, and for the negotiation process in which the cognitive system adopts a perspective and adapts it to the data, a process which results in categories with family resemblance structures.

Thus the crucial differences between this adaptive model and the similarity-based model in general can be summarized as follows:

1) Similarity-based models do not explain why certain dimensions are selected for similarity comparison, while the adaptive model operating within the posited framework of knowledge development can account for the constraints of attribute selection.

2) Similarity-based models use visual stimuli with no knowledge depth attributable to them. As a consequence, they allow only innate perception, or what Quine calls the "innate standard of similarity" in the process. This innate perception-alone-approach restricts the study to pattern recognition type of research, which is inadequate for knowledge rich areas. The adaptive model with the two additional variables (i.e. the pre-existing knowledge and goal specified at a cognitive level) can account for categorization in the knowledge rich area.

3) Whereas similarity-based models cannot get people to produce FR categories and the two-stage model looks for stronger constraints in the stimulus set, the adaptive model relies on internally generated constraints.

4) Similarity-based models hold that prototypes and the family resemblance structure result from extracting the central tendency of the objects, while the adaptive model maintains that prototypes and family resemblance result from the projection

of information in the experience field under the appropriate constraints and the need to adapt to the data.

To what degree do our experiment results support the adaptive model? Assuming that family resemblance is a good indicator of category structure, we are able to make the following claims with the experimental results.

1) The experiment results clearly show that the pre-existing knowledge and goal play an important role in categorization. This is shown not only in the results in C1 and C4 in the first experiment and C1 and C2 in the second experiment, where the absence and presence of the two variables account for the difference in results, but also in C2 and C3 of the first experiment where the absence of either variable renders the presence of the other inoperable in terms of creating FR categories.

2) The preference rule-based interaction is supported in that subjects clearly base their judgment not on the perceptual criterion but on the perspective derived mainly for the understanding of the attribute functions and the goal. In other words, the pre-existing knowledge goal-based constraints override the criterion of innate perception. This can be clearly observed in the protocols of the experiments, where if subjects were not given the pre-existing knowledge or goal as in C1 of the two experiments, they used the perceptual criterion. In C4 of the first experiment and C2 of the second, where the two variables were present, the perceptual criterion was overridden and replaced by that derived from the pre-existing knowledge goal for sorting.

3) The negotiation process is also supported. Again in C4 of the first

experiment and C2 of the second, to create FR sorting, subjects must adapt the perspective to the data which deviates from the two prototypes to varying degrees, and in adapting they must seek maximum consistency with the prototypes. Without this negotiation process, FR sorting would not have been produced.

Taken together, the experimental results support the assertions that similarity should and can be constrained, that the constraints should be generated from the internal structure of the cognitive system in terms of the pre-existing knowledge and goal instead of through manipulating the exemplar sets, and that people do not automatically extract central tendency when provided with a set of exemplars. In fact, people create categories for the pragmatic purpose of using the categories as functional units in cognitive operations. The central tendency is observed when we examine the existing categories, for, as we said in Chapter 3, all categories are projections of information elements. As such, their prototypes are surrounded with less typical members and categories are surrounded with unprojectible information elements -- a structure, which, interesting in itself, should not be seen as indicating how categories are formed. It is far more important to ask the question of why certain information elements get projected and encapsulated in the categories while others are left out.

To what degree can we claim that people create FR categories using the process described in the adaptive model? We cannot give a complete and conclusive answer to this question now, for the adaptive model needs to be further tested, and tested in knowledge-rich domains. Furthermore, better control must be devised to ensure that information presented as the pre-existing knowledge and goal is acquired by subjects and that subjects are aware of the constraints throughout the categorization process. But for now, these experiments have shown that the model is certainly capable of accounting for the generation of FR categories. It captures cognitive process better than the similarity model and the two-stage model for two reasons. First, it is more robust in producing FR categories as it generates FR categories with the exemplar sets with which the similarity model and the two-stage model cannot. As the family resemblance structure is widely observed in natural categories, this more robust model captures the nature of categorization better. Secondly, compared with the account of FR structure given in the similarity model and the two-stage model, the account of the family resemblance structure given in the adaptive model is closer to the cognitive process of categorization. The three components of the model, namely, the experience base, the preference rule-based interaction of the three variables and the negotiation process account for the source of data to be categorized, the creation of appropriate constraints for similarity comparison in categorization and the source of family resemblance structure.

At the theoretical level, the adaptive model, apart from satisfying the condition of family resemblance structure, has a better promise of satisfying another condition of an adequate model of category construction. The condition is that an adequate model should be able to generate categories at different cognitive levels. This condition can find support in both empirical observation of categories and discussions in philosophy and cognitive science literature. Quine (1977), for instance, argued that children begin with innate, perceptually based similarity metrics to define their kinds, only to have them successively replaced by scientific knowledge to the limits of their education and our scientific progress. No category construction models have ever considered this condition while the adaptive model with its knowledge framework are specifically developed to meet this condition.

However, due to the use of artificial exemplar sets, pre-existing knowledge and goal, the experiment results cannot support the claims and assumptions in the knowledge framework. First, the presumed interrelatedness and integrity among the pre-existing knowledge, goal and data cannot be ascertained and supported, since in the experiments, the pre-existing knowledge, the goal and the exemplars were all designed by the experimenter, assuming that the data, knowledge base and goal are appropriate for each other and at the same cognitive level. Second, the cyclic progression hypothesis cannot be rejected or supported, for the experiments tested only the conceptualization stage of one cycle at a particular cognitive level. Therefore, the presumed relationship between unperceived reality, unprojectible information and projected information in the existing categories cannot be shown in these experiments.

Explanation was given for the 9 1-D sortings in C2 of the second experiment in the analysis of protocols. The analysis shows that the adaptive model in an experimental setting needs better control in two phases of sorting.

Firstly, better control is needed in helping subjects acquire information necessary for conceiving prototypes and constraints. For instance, in the experiments, subjects acquired information on the attributes and goal through 5-10 minutes reading while in real life, people acquire the pre-existing knowledge which they bring to a categorization task during a much longer time. It may take some people longer than 5-10 minutes to let information sink in and to notice the requirement. It may be due to insufficient time for acquiring the information that three subjects misunderstood the information and presumed things not given in the reading passage. Better control can be achieved by presenting the relevant information to the subjects the day before the subjects come to the sorting task and by testing them to see if they comprehend the information correctly on the day of experiment. Subjects who do not have the correct information should either be presented with the information again and tested or be excluded from the experiment. Providing a longer time for the information to sink in is necessary because the subjects will not just be required to passively retain the information. They will rearrange and evaluate the information, and integrate the information with the goal to form constraints in the sorting task. In a word, they will operate with the information. Furthermore, given a usual exemplar set of ten to sixteen exemplars, each with four attributes varying among the three values, subjects have quite a large information load in processing the data. Therefore, presenting the pre-existing knowledge information in a previous session would avoid further increasing the information load at the sorting time.

Secondly, better control is needed to help subjects observe the constraints in sorting. Five subjects in C2 of the second experiment formed prototypes and needed constraints, which they then did not actually observe in sorting. A feedback loop may be needed to let subjects know the effect of their sortings. In real life, categories are often revised or discarded upon observing the effect of the categorization. For instance, assigning E5 to gatherer group and E13 to guard group would not give the maximum efficiency needed for the survival of the kangaroo group. If subjects get this feedback, they may reexamine their sortings.

## 5.2 Implications of the Framework and the Adaptive Model for Educational Technology

Implications can be discussed in two ways. Usually, researchers will discuss implications that can be strictly supported by the results of experiments. This approach usually limits the discussion to a specific part of a process, for issues that can be dealt experimentally are very limited and specific. As a result, one rarely sees how the conclusion statements supported by the experiments would fit in the larger process. In the following discussion, I will present the implications of the experiment results for teaching concepts in Section 5.2.4 "Conceptualization Process", which examines the current instructional strategies and identifies the need for fostering learner appreciation of constraints and perspective in concept learning as basis for formulating instructional strategies. The discussion is based on the experiment results. However, attempts are also made to discuss some related issues from the theoretical perspective of the framework of knowledge development. This part of discussion does not have the support of the experimental results. It is meant to lead to "Conceptualization process" and to demonstrate that the framework and adaptive model can offer a new perspective on these issues.

Specifically, three sections belong to this type of discussion: "Two commonalities between concept formation and concept learning"; "Account for the lack of relevance of research on concepts to concept teaching"; and "The issue of expanding the experience base for learning new concepts".

Three concept-teaching models merit attention. They are Klausmeier's model (Klausmeier & Frayer, 1974; Klausmeier & Goodwin, 1975; Klausmeier 1976; Klausmeier & Allen 1978); the model of Merrill and Tennyson (1977) and its second edition (1992); and the model of Tennyson and Cocchiarella (1986). These models are chosen because they are the major instructional models for concept teaching and they all incorporate views and theories on the nature of concepts and concept formation from research on concepts in cognitive psychology. Klausmeier's model is identified with the classical theory of concept, Merrill and Tennyson's instructional design guide incorporates the prototype theory and the model developed by Tennyson and Cocchiarella incorporates not only the view that categories possess family resemblance features but also the hypothesis of central tendency through similarity judgment. In addition, Tennyson and Cocchiarella's model claims to be based on direct empirical validation from a programmatic line of instructional systems research.

### 5.2.1 Two commonalities between concept formation and concept learning

As stated in Chapter One, concept formation is a process in which the cognitive system goes through all the stages in creating new concepts, including exploring new environment, observing new phenomena, formulating constraints and organizing data and finally testing the concepts in problem solving. The concepts thus formed may not exist or the cognitive system may not be aware of the concepts if they do exist. Concept learning, on the other hand, refers to acquisition of concepts through instruction or other types of communication. Typically, the cognitive system does not go through the process of organizing the data. The learner is presented with structured data together with the labels for the concepts.

An educational system is charged with the "responsibility" to see to it that the young generation inherits these types of concepts. The learning of concepts used in everyday life is often talked about as "vocabulary learning". But psycholinguistic research (e.g. Clark and Clark, 1977) has repeatedly shown that much of children's early language learning is actually concept learning just as is the learning of scientific concepts in school and universities.

As described in the knowledge framework in Chapter 2, concept formation is an integral stage of knowledge development. This relationship is mirrored in concept learning and knowledge learning. Concept learning is a part of the learning process to acquire knowledge, because the understanding of principles, laws and theories in sciences must be based on the understanding of the relevant concepts. Therefore, while concept learning is a contributing part of theory learning, especially in science, theory learning is a context for concept learning. The two sets of relationships can be put in the following way (see Table 5.1 on the next page).

| A. Theories of knowledge | B. Theories of instruction |
|---|---|
| Knowledge development | Learning of knowledge through instruction |
| Concept formation & categorization | Concept learning through instruction |

Table 5.1. Categorization and Its Relationship with Knowledge Development and Learning

The differences of the two modes of knowledge acquisition are obvious. The most important one is perhaps that knowledge development is self-guided and exploratory whereas knowledge learning is structured and guided by instruction. For instance, the history of science has been marked by successive overthrows of widely accepted views of nature. New theories are generated from within a science community which collectively undergoes a change in conceptual system. By contrast, change of conceptual system in learners is helped by instruction and planned in the curriculum. Hence, educational research has two extra sets of variables: learner variables and instructional strategy variables. The advantage of "knowledge learning" is in the efficiency of knowledge acquisition.

However, it is the commonalities of the two modes of knowledge acquisition that we are more interested in, for the commonalities help us identify areas where research can be mutually useful. For the purpose of this project, two commonalities are identified.

One commonality is captured by the cognitive levels of the knowledge framework. In those well-organized knowledge domains, hierarchical structure of knowledge requires the learner to go through the similar kind of changes in conceptual system that a science community went through in the course of developing the knowledge in the domain, except those digressions and theories that later did not serve as scaffolding for higher order conceptualization. There are some interesting characteristics associated with both processes of conceptual system changes, which suggest that they are more than coincidence. First, students often enter a science course with views that parallel an earlier conception of the field (Eylon & Linn, 1988). For example, students' everyday conception of mechanisms often echo an observation of Aristotle: Students believe that objects follow their destiny. McClosekey, Caramazza, and Green (1980) found that students expect balls to continue on curved paths when released from circular motion. Di Sessa (1988) reported that students expect objects to move in the direction they are pushed, even when they are already in motion. Some concepts of heat also resemble the caloric theory of the 18th century, the view of heat as a substance that can be added or subtracted. These studies appear to indicate that learners have to undergo the similar kind of conceptual changes that a science community has collectively gone through. It may also be interesting to note that both a science community and learners start from the same original intuitive conceptualization of the domain, which we have referred in this study as the basic cognitive level mental models.

Furthermore, it is found that students are very resistant to the change of their intuitive conceptual system (Burbules & Linn, 1988; di Sessa, 1982; Minstrell, 1982, etc.). Students defend their views fiercely and can and do ignore contradictions to their belief. They even hold contradictory multiple conceptions. This kind of resistance resembles many fierce battles, persecutions and imprisonment of scientists at a societal scale in the course of knowledge development, especially in the early days of science when an existing conceptual system was threatened by a new one. Can resemblances like these between the course of knowledge development and students' learning process suggest something about knowledge structure and human cognition?

The other commonality is at the level of concept acquisition. Whether concepts are formed as part of knowledge development by scientists and researchers or learned in a process of training by students, some essential aspects are the same as those captured in the adaptive model. They can be represented by the following questions. For a set of concepts to be formed or learned, what are the data to be categorized? Where do the data come from (i.e. what prerequisite knowledge does it take for a person to perceive the data? What variables are involved in categorization? What are the general features of the concepts formed or learned and how useful are they in advancing the understanding of the domain and in solving problems in the domain? As these questions can be asked of both concept formation and learning, their answers should apply to both.

### 5.2.2 Account for the apparent lack of relevance of research on concepts to concepts teaching

Given the two commonalities between concept formation and learning, one expects that research on concepts and concept formation must have a lot to offer to education, especially in the area of instructional design for concept teaching. On the other hand, educational research on concept teaching has accumulated its own literature. One would expect that instructional models would have substantial cognitive theoretical foundation. Unfortunately, even a cursory browse of the literature makes one realize that help from research on concepts is limited primarily to the characteristics of concepts, namely, the family resemblance characteristics. There appears to be very little in the area of concept formation that conventional psychology can offer to instructional design.

From the viewpoint of our knowledge development, the reason for this lack of progress in concept formation is that psychological research has remained with the strategy of using only artificial stimuli, and with the pre-existing knowledge and goal excluded from consideration of concept formation. Consequently, research on concepts and concept formation is conducted on a single cognitive level because artificial stimulus sets do not have knowledge depth, for artificial stimuli have no unobservable features. Without understanding the role of the pre-existing knowledge in concept formation, research in this area remains largely a study of stimuli grouping by innate perception. From the viewpoint of concept teaching, this type of research cannot offer substantial insights to guide teaching, for concept learning always involves the pre-existing knowledge of the domain. In other words, single cognitive level research practice not only could constitute a roadblock for the progression of basic research on concept formation, but may also be a cause for the lack of relevance to concept teaching in education.

In the area of instructional design for teaching concepts, the same single cognitive level research practice appears to be the general state of affairs. All of the three instructional models reviewed treat the cross-level issue by simply assuming that the instruction starts with the prerequisite knowledge, making no provision to facilitate the formation of constraints and perspective for reclassifying the domain. Rather, research is concerned with the strategies of presenting the concepts, and with methods to stress critical attributes for learners. Consequently, researchers focus on the techniques and devices for selecting examples and nonexamples, on deriving and presenting definitions, and on the relationship between definitions and examples etc..

But the cross-level issue requires more than simply stating that learners need prerequisite knowledge to acquire certain concepts. If instruction is to be effective, one must look into the cognitive conditions of the learner and ask the following questions:

-- Is the learner's existing conceptual model sufficient for perceiving and experiencing the new phenomena so as to expand the experience base to the extent needed for the acquisition of the new concepts? (This question addresses the source of data to be classified.)

-- How can the learner be helped to formulate goal(s) and to activate the appropriate pre-existing knowledge so that the learner will come to the concept learning task with an appreciation of the relevant constraints and perspective already built into the concepts to be learned?

-- How can the learner be helped to see that the perspective has to adapt to the data in order to subsume them to the sufficient extent to achieve the goal(s), and consequently, categories formed have more and less typical members?

These questions get to the cognitive process of concept formation and can be asked and researched only when concept formation is seen in the context of multi-cognitive levels. For instance, to appreciate the relevant constraints and perspective, in other words, to see why a particular set of attributes were selected for the categories, the learner must activate his/her pre-existing knowledge at an appropriate cognitive level.

**5.2.3 Expanding the experience base**

The learner's awareness or experience of the domain reality must be expanded in order to have a necessary experience base for reconceptualization. The expansion is usually in the micro direction for adults who have attained the normal and non-specialist conception of the domain. The learner has to experience and perceive a new set of phenomena in the domain before he/she can be expected to see the rationale of the reclassification, for the new conceptualization is based on the new set of phenomena. This is a step when the learner's existing conceptual model is brought to confront the new set of phenomena, for which it is not adequate to provide an account. Hence, a need to reconceptualize the domain is created. In short, the experience expansion accomplishes two objectives: to create an expanded experience base and subsequently to create a need for reconceptualization.

Two points need to be briefly discussed here, both of which have important implications for instruction: 1) arranging an environment for expanding experience base, and 2) the scope of experience expansion.

First, depending on the subject matter, an environment for expanding experience can be arranged in real world situations such as field trips, or in labs where the phenomena can be demonstrated and observed, or through verbal description of the phenomena as many textbooks try to do when introducing new concepts. However, these arrangements are not equally effective or efficient. The most effective arrangement is the experience gained in real world situations where phenomena occur naturally. Note that to observe naturally occurring phenomena may need technological help such as microscopes and computer simulations. So expanding the range of perception and interaction and arranging a particular mode for gaining the new experience base are two different things. Observing naturally occurring phenomena is less efficient than other arrangements, for there is no control over phenomena occurrence or noise stimuli which may interfere with the observation of the phenomena. Under lab conditions, phenomena are made to occur.

Here, phenomena are more focused than those in the natural environment and the variables are clearly distinguished from noise stimuli. But lab conditions do not have the dynamics of the natural environment. Verbal description appears to be the most efficient of all. It has the advantage of working almost directly with the linguistic system. Observations in both natural environments and labs will have to be processed to be represented mostly in linguistic symbolic system in the mind. However, this advantage comes with a huge risk in that the learner may not be able to make the connection between the verbal description and experience, in which case, the description fails to be meaningful to the learner. Furthermore, it is not known that to what extent linguistic symbols can create new experience rather than just reorganize and give new focus to the existing experience. In an instructional situation, different arrangements should be used complementarily to ensure both effectiveness and efficiency.

Second, even though the learner has to break through the existing conceptual model, the existing model has a crucial role in expanding the experience base, namely, it enables the learner to perceive new phenomena. By the same principle, there is a limit of scope in expanding the experience base. That is, not all phenomena known to experts in the domain are accessible to the learner. The perception and experience of some phenomena of the domain requires the conceptual model at a higher level than the existing one in the learner.

### 5.2.4 The conceptualization process

The necessary cognitive conditions of the learner at this stage can be characterized by the following: First, the learner has an existing conceptual system of the domain, which he/she has found to be inadequate. Second, the learner has an expanded experience base of the domain sufficient for forming the concepts of the conceptual model at the next higher level. Third, the learner is aware of the tasks he/she is expected to perform. The tasks can be performed only with the new conceptual model. With these characteristics, the learner is ready to form new concepts.

None of the three instructional models reviewed give extensive description of the conceptualization process. Klausmeier's model implicitly subscribes to the similarity theory which simply says that concepts are formed by similarity judgment.

No attention is given to the issue of in what respects things are judged similar. Merrill and Tennyson's guide offers no explanation to the concept formation process. In Tennyson and Cocchiarella's model, Rosch's central tendency through overall similarity judgment is invoked as the model of concept formation. But Rosch's hypothesis that categories are formed by abstracting central tendency of the stimuli through overall similarity judgment is not supported by earlier empirical studies (e.g., Medin et al., 1987) nor by the experiments in this project. Its theoretical deficiency is that similarity does not explain why we have the categories we have, for it does not explain why we choose certain dimensions of objects along which to judge the similarity (Medin, 1989, 1993).

As described in Chapters 2 and 4, the crucial point in the study of concept formation is to account for the deriving of appropriate constraints for the selection of attributes. In designing instruction for concept teaching, the issue is how to enable learners to appreciate the constraints and perspective employed in the formation of concepts. In other words, learners should see why we have the concepts we have. The effort to expand learners' experience base is in fact part of the work to help learners achieve this appreciation.

Keeping in mind the need to help learners appreciate the constraints and perspective of the concepts to be learned, we can discuss three important issues in instructional design that have been debated in the literature. 1) Is concept learning best facilitated with definitions or examples? If both definitions and examples are needed, when are examples more effective than definitions and when are definitions more efficient than examples? 2) How can the learner's attention be drawn to the critical attributes? 3) How can the learner be helped to form concepts with the right extent of dispersion so that the learner will neither overgeneralize nor undergeneralize categories?

**5.2.4.1 Examples and definitions**

In devising strategies to facilitate concept learning, it is worth noting a shift in the role assigned to definitions and examples. In the 1970s, many studies (e.g. Klausmeier,1976; Merrill & Tennyson, 1978; Anderson & Kulhavy, 1972) put emphasis on providing definitions, based on the assumption of the classical theory that concepts are a set of necessary and jointly sufficient features. As definitions explicitly specify the attributes, they were seen as the most effective instructional strategy. Frayer (1970), for instance, found that providing a concept definition could significantly reduce the number of examples necessary to master the concept. Klausmeier and Feldman (1975) found that definition provided about the same amount of learning facilitation as one rational set of examples and nonexamples. The general consensus at the time seemed to be that definition could short-circuit the hypothesis testing process (Klausmeier & Hooper, 1974, p.38) but examples were needed to prevent students from merely memorizing a string of verbal associations. In the 1980s, the assumption in the model by Tennyson and Cocchiarella (1986) was that of the similarity model. "In summary, the common theme in Rosch's work on relevant prototype research is that learners acquire conceptual knowledge around a central abstraction of the category." (p.51) The instructional strategy based on this assumption is the use of best examples for acquiring conceptual knowledge, because best examples are the clear cases of a category, representing the central tendency of the semantic space covered by the category. Thus, the best examples display most of the critical attributes of the category. Tennyson, Youngers and Suebsonthi (1983) and Park (1984) conducted experiments which all found that providing best examples was a better strategy than using definitions.

The shift made progress along with the changes in theories of concepts. However, the assumptions on concept formation in both classical and prototype theories are being challenged.

In terms of empirical research in instructional design, the problem is that definitions and examples are compared and studied without specifying the conditions of learners. Without specifying under what conditions the effects of definitions and examples are observed, one can produce inconsistent empirical findings. Thus definitions can provide a short circuit for hypothesis testing and reduce the number of examples needed for concept attainment. Yet best examples are found to be more effective than definitions in developing conceptual knowledge. There are empirical studies which even found the optimal number of examples to be about four (e.g. Clark, 1971) and studies which found that definitions provide the same amount of learning facilitation as a rational set of examples. Each of these statements may be true under certain conditions and yet together, they lead one to make contradictory instructional prescriptions.

<u>Tasks</u> From the view point of the adaptive model, instructional strategies for

this stage should be based on helping the learner process the data in the expanded experience base. As this is a case of concept learning instead of concept formation, learners need to process the data to be able to appreciate the constraints and perspective rather than to actually form concepts.

However, neither examples nor definitions are appropriate in motivating the learner to process the data and thereby to appreciate the constraints and perspective. According to the adaptive model, the constraints are derived from the preference rule-based interaction of the three variables. In both the experiments in this study, it was found that only the conditions with both the pre-existing knowledge and goal could provide appropriate constraints. In concept learning, learners need to acquire similar internal conditions in order to see why the concepts they are learning should be there. That is, a condition similar to C4 of Experiment One and C2 of Experiment Two must be created in the learner's mind for him/her to really understand the concepts being learned.

To create such a condition, instruction must provide a goal or task, for the pre-existing knowledge and innate perception are already there. The significance of the goal is that it activates the learner's pre-existing knowledge and makes him/her examine the data in the experience base on those terms. Of particular interest is C2 of Experiment One where the pre-existing knowledge was given but not the goal. Subjects either supplied their own goal or made no use of the pre-existing knowledge, and as a result, no FR categories were produced.

Elsewhere, tasks are also used as a fundamental instructional strategy. For instance, Harri-Augstein and Thomas (1991) hold that tasks can best let a person be self-organizing. With the data, the pre-existing knowledge, and the goal, the conditions are created for achieving an appreciation of the constraints and perspective. In a way, it matters more that learners go through a similar process of concept formation to have an understanding of the constraints than that they actually come up with the right concepts. In fact, most categories and concepts in theories are formed over a long period of time and only relatively few can create concepts which gain acceptance.

Tasks should be designed in the instruction instead of being left for the learner to conceive. Tasks or goals should be appropriate and manageable to learners. That is, the accomplishment of the task requires the concepts to be learned.

Examples, definitions and names The use of task is a bottom line approach and may not be as efficient a strategy as the use of examples or definitions under certain conditions. After all, one purpose of organized learning is to gain efficiency. If it can be assured that learners can appreciate the perspective and constraints and thereby understand why we have the categories we have through examples or definitions, then the strategy is to use examples or definitions. The use of both examples and definitions saves the learner the actual processing of the experience data. They present to the learner the products of that process, i.e. the formed categories. Therefore, they appear more efficient.

Using examples skips the learner's mental process of deriving a perspective and constraints. Yet, a true understanding of the concepts requires and includes the understanding of the constraints and perspective. Thus, if the learner does not go through this mental process in task-oriented instruction, he/she has to infer the constraints and perspective through examples on their own. This is why the use of examples is not as effective as the use of tasks. However, examples being the concrete cases of a concept are more transparent than definitions in reflecting the perspective adopted and constraints observed in the classification process. Furthermore, depending on its typicality, an example may not have all the attributes and may have attributes that other examples of the category do not have. Thus using a set of examples with varying typicality and nonexamples can help learners abstract central conceptual knowledge.

Definitions are already abstract. They focus on identifying the semantic location of the category in a semantic/conceptual field by specifying relations with the superordinate and its unique properties to distinguish it from coordinate categories. Definitions therefore are more efficient for acquiring the semantic content of the category than examples by saving the learner the process of doing the abstraction. Actually along the effectiveness and efficiency scales there is one more item, the name or label of the category. The name is the most efficient in delivering the identity of the category in a lexicalized form and the least effective in reflecting the rationale of the category. There are times when the learner is intimately familiar with the phenomena and can immediately appreciate the perspective in classification. All the learner needs is a term to give the semantic contents of an identity.

Tasks, examples, definitions and names are thus inversely related on the effectiveness and efficiency scales. Tasks and examples work with experience at a low level of abstraction. Definitions and names work with linguistic symbols at a high level of abstraction. A general principle of instructional design would be: to go as low as necessary to ensure effectiveness and as high as possible to improve efficiency. The selection of any of these or combinations of these strategies depends on the conditions of the learner. Optimal combinations of these strategies based on learners' conditions should be researched and explored.

#### 5.2.4.2 Critical attributes

All three conceptual teaching instructional models put emphasis on drawing the learner's attention to the critical or defining features of the concepts being learned. Merrill and Tennyson's guide, for instance, advises using devices such as color, exploded drawings, special symbols etc. to isolate and stress the critical features. These are obviously good and useful devices. However, the question is whether instructions should always depend on these devices for emphasizing the critical attributes. Instructions would depend on these external devices only if concepts are presented with a set of attributes, without considering whether learners possess the needed experience base to construct meanings with the names of the concepts. There is nothing wrong with this symbol-based approach. However, an instructional design model should first of all ground itself on the experience-based approach. In other words, it should concentrate on creating learners' internal conditions to focus the learner's attention on the critical features of the concepts being learned. Only when it is assured that the learner's experience base is sufficient and that the learner can appreciate the perspective and constraints in the classification, can instruction consider the symbol-based approach.

How can instruction create an internal condition which will focus the learner's attention on the critical features of the concepts? The two experiments showed that the preference rule-based interaction would derive a set of constraints which will guide the selection of attributes. For instance, in C2 of Experiment Two, the pre-existing knowledge and goal combined to produce a perspective which guided subjects to select the four relevant features of the kangaroos and ignore the two irrelevant features in sorting. Similarly, in Experiment One, subjects in C4 derived the perspective to guide their selection of feature values to produce FR sortings. In concept learning, a similar internal condition is needed in the learner to focus his/her attention on the critical features. In fact, if the learner has derived or can appreciate the constraints and perspective, he/she knows not only which features should be noted but also why these features must be there. The need of external devices such as color and exploded drawings should only be supplementary.

#### 5.2.4.3 Example dispersion

Research in psychology demonstrates the prevalence of family resemblance characteristics among natural categories. That is, members of a category may differentially possess the attributes of the category and share attributes with members of contrasting categories to a varying extent. Members of a concept are not equally representative of the concept. They can be rank ordered along a typicality scale. What is more, the line between the least typical members and some nonmembers is not always clear. These characteristics of concepts impose questions for instructional designers. For example, should instruction use highly similar and clear examples (narrow dispersion) to help the learner form prototypes? Or should instruction use examples ranging from the prototype to the least typical ones (wide dispersion) to help the learner acquire the full range of the conceptual/semantic space?

In the model by Tennyson and Cocchiarella (1986), the authors advise the use of the best examples for developing the conceptual knowledge. Ranzijn (1990) ran an experiment on the effects of example dispersion. He found that narrowly dispersed examples are better for developing declarative knowledge because they focus on the critical attributes better, while widely dispersed examples are better for developing procedural knowledge because they provide a wide range of the concept members. The subjects thus can classify more accurately.

Both the strategy in the model and research finding obviously make sense. The point I want to make is complementary, as an attempt to put the question of example dispersion in a larger context of the knowledge framework. The question of example dispersion arises only when the instruction is example-led, when the learner depends mostly on examples to acquire the concept. Then instruction through presenting examples is based on the hope that learners would perceive the perspective implied in the very selection of the examples and then extract the attributes from the examples. As examples can range from the most to the least typical with varying potential for attributes abstraction, the question of dispersion has to be dealt with. The most typical examples would obviously better help learners to abstract the critical attributes and the least typical examples are needed to help the learner delineate the boundary of the concept. Therefore both types of examples are needed, but perhaps at different stages of instruction.

What would happen if instruction mostly uses definitions, and examples are used only supplementarily? Here the question of dispersion is obscured because the process of abstracting attributes is omitted, as attributes are presented in definitions. Thus instructional models such as Klausmeier's, which put emphasis on definitions, do not have this question in view. This also explains why definitions are more superficially efficient but less effective than examples.

On the other hand, instruction led by tasks/goals does not raise the question of example dispersion either, not because it is obscured, but because it is taken care of. The task-led instruction does not omit any process. The learner actually has to go through the experience data processing with the adopted perspective and constraints. In the process, learners will encounter objects or exemplars which fit the perspective and satisfy the constraints perfectly; these are the prototypes or typical members of the concepts. However, learners will also encounter exemplars which do not fit the perspective well; but these data must be processed to achieve the goal. If the learner goes through this process, actually making a decision on the cutline between members and nonmembers, instruction does not have to deal with the example dispersion problem. Learners know the extent of the concept's semantic space. Again, it is more important that the learner actually processes the data and makes the decision on the cutline than whether he or she gets it right.

## 5.3 Summary

Concept formation and concept learning as studied in cognitive psychology and in instructional design involve cross-level variables, namely, the pre-existing knowledge and goal. Excluding these variables results in the inability of category construction models to generate FR categories and demands reliance on external, artificial devices to help learners acquire concepts. The framework of knowledge development we have proposed in this study enables us to bring in the two missing variable sets and the adaptive model of category construction illustrates the process of categorization with these two needed variable sets interacting to provide constraints for the selection of attributes.

With our framework and the adaptive model, we discussed two phases in concept teaching: expansion of experience base and conceptualization process. A number of instructional issues were examined such as the possibility of motivating learners to overcome their resistance to reconceptualization, roles of tasks, examples and definitions, strategies to focus the learner's attention to the critical attributes, and finally, the dispersion of examples. We were able to look at these instructional issues from a new and consistent perspective and provide a connection to these issues. For example, instead of being seen as separate items, tasks, examples, definitions and names of concepts have different roles along the effectiveness and efficiency scales. Furthermore, we showed that there are intrinsic mechanisms to focus the learner's attention to the critical attributes and that external, artificial devices should have only a supplementary role. I believe that the knowledge framework has a great potential in providing insights to instructional design issues. The issues discussed in this chapter represent only the first such attempt to relate the results to instructional design.

# CHAPTER 6

## SUMMARY AND SUGGESTIONS FOR FURTHER RESEARCH

### 6.1. Summary

The present research interest on categorization comes from a number of directions. Quine (1977) outlined a research program on the progression from the innate similarity judgment to theoretical kinds and similarities. Quine's view was supported by Murphy and Medin (1985) in their argument for incorporating theoretical knowledge in the study of categorization as similarity is found in need of specifying respects. Medin has continued this line of argument right up to the present (e.g. Medin, 1989, 1993). Carey (1985) confirmed that radical conceptual change occurs in children between 4 and 10 years of age. The next step would be to explain the mechanisms of this conceptual change. In addition, linguists like Lakoff (1987) and Jackendoff (1983) and semanticists all have an interest in the study of categorization, for an account of a language's lexical system must include theories of categorization. Finally, as the study of categorization and concept formation is part of the research on learning, theories of categorization will have an impact on educational research in general and on instructional design for teaching concepts in particular.

The main contributions of this thesis work can be summarized as follows:

-- The most direct contribution is that our new adaptive model provides a better account for categorization behaviour. Family resemblance, typicality and prototype are seen here as properties that natural categories exhibit and need explanation of. The strength of the adaptive model is derived from the incorporation of the pre-existing knowledge-goal generated constraints inside the cognitive system doing the categorization.

-- Our adaptive model is robust. It can generate FR categories with exemplar sets that the two-stage model cannot. Considering the prevalence of FR properties in natural categories, the robustness is an important advantage.

-- On a more substantive aspect, this adaptive model and its framework give a coherent account for family resemblance, typicality and prototype properties. In other words, the model offers an account for categorization, which specifies the mechanisms for generating constraints (i.e the preference rule-based interaction among the innate perception, pre-existing knowledge and goal) in selecting information elements to be projected as category attributes. Furthermore, the model's negotiation component reveals the nature of information projection in that the projection is rarely neat. Hence, the cognitive system must adapt to the data, resulting in FR categories.

-- The hypothetical knowledge framework configures cognitive levels and stages for conceptualization orthogonally in the form of polar coordinates. The conceptualization process has been widely discussed in the literature (e.g. Jackendoff, 1983; Leech, 1981), so have various notions of cognitive levels. For instance, Rosch and her coworkers proposed the notion of basic level categories. The notion of basic level is close to the basic levels of the knowledge framework, although the idea of cognitive levels in the framework is explicitly grounded on the range of human perception and interaction with the environment. However, configuring the two constructs orthogonally in polar coordinates is unique to this framework. The significance of such a configuration is that it reveals the spiral form that knowledge development takes. That is, the stages of conceptualization enable cognition to progress across the levels while successively higher cognitive level explains the source of data (i.e. new experience) for continued conceptualization.

-- The role of pre-existing knowledge has been increasingly noted and acknowledged by researchers in this area. However, to this date the pre-existing knowledge and goal have not been used as variables in categorization studies, as the incorporation of the two variables requires stratifying knowledge, especially if the study is to be conducted in knowledge-rich domains. The adaptive model and its framework have the potential of developing an approach to stratify knowledge and thus make it possible to incorporate the pre-existing knowledge and goal at the required cognitive level.

-- The framework and the adaptive model may offer an explanation for the so called "gravitation" effect of the basic level conceptual system. Such a gravitation effect has been observed in both child development where all normal children go through radical conceptual change to attain the basic level conceptual system and in science education where students are found resistant to the change of basic level conceptual system. Our hypothetical new explanation, which depends on the four factors outlined in Chapter 5, is again grounded on the range of human perception and interaction with the environment.

-- Finally, let us return to the larger context of research interest. Carey (1985), after presenting extensive evidence on the conceptual change in children from the age of 4 to 10, noted the need to explain the change: "Many students of development decry our lack of explicit theories of mechanisms for change. Although the explanation of change is important, clearly the description of change must come first, or at least in tandem with the search for mechanisms." (p.200) Quine (1977) outlined a research program when he argued for a progression from innate similarity judgment to theoretical kinds and similarity judgment: "Between an innate similarity notion or spacing of qualities and a scientifically sophisticated one, there are all gradations." (p. 167) Quine's interest is in the mechanisms which explains the progression from the innate similarity judgment which focuses on the surface features, to scientific theory-based similarity judgment which focuses on underlying and unobservable features. In other words, the mechanisms must specify how to derive successively more insightful constraints based on the theoretical knowledge at successively higher level in selecting properties for similarity judgment.

The knowledge framework and adaptive model can be seen as a piece of work contributing to the psychological research program, for they have outlined a workable scheme for deriving successively more insightful constraints for categorization behaviour.

## 6.2. Further Research

The knowledge framework and the adaptive model proposed in this thesis project makes a number of theoretical claims which should be tested.

### 6.2.1. Further research on the adaptive model

First, the adaptive model claims that FR categories are formed as a result of the cognitive system adapting its perspective to the data in the experience base. The perspective is derived from internally generated constraints formed with innate perception, pre-existing knowledge and goal. The two experiments in this project tested only the roles of pre-existing knowledge and a goal in generating FR categories. Although by analyzing the protocols, we can generally see if the subjects have formed the necessary constraints and derived the perspective in the form of prototypes for categories, such experiments cannot demonstrate that the subjects really went through the cognitive process which the adaptive model describes.

To further test the adaptive model, a number of additional measurements should be taken, beyond the proportions of FR categories created. These measurements can all be encompassed in the adaptive model as follows. Given the pre-existing knowledge and goal for the sorting task, and a set of exemplars varying systematically in the features they possess, the adaptive model says that the cognitive system will form a set of constraints from which a perspective is derived for sorting.

In this process, the cognitive system selects relevant attributes and weighs the importance of possessing certain attributes or attribute values. More specifically, the model performs two ratings of each attribute value. In the first rating, it rates the relevance and importance of each attribute value for an exemplar to possess in order to be assigned to each of the potential categories. To use the material of the second experiment as an example, if a kangaroo possesses long horns, is this attribute value relevant to the guard category? Or to the gatherer category? If it is relevant to the guard category, how important is it? In the second rating, the model rates the unfavourableness of an attribute value possessed by an exemplar in assigning it to each of the potential categories. For example, the attribute value of no hair may be seen as very unfavourable for assigning a kangaroo to the gatherer category. With the data from the two ratings, a decision rule can be applied to determine which category an exemplar should be assigned to. For instance, in a case where there are two potential categories, a particular exemplar may possess attribute values of both categories. If attribute values of category A outweigh those of category B, the exemplar is assigned to category A. If otherwise, the exemplar is assigned to B. As a result, the model can predict not only which exemplar will be assigned to which category but also the degree of typicality of an exemplar in its category. That is, the greater the outweight value in favour of a category, the more typical the exemplar of that category is. The least typical exemplar would have the smallest margin of outweight. Thus, the model can generate three sets of measurements: attribute value rating, sorting prediction, and typicality rating. They are the predicted values.

The experiment would require subjects to perform three tasks.

1) Rating attribute values. After being presented with the pre-existing knowledge information and goal, subjects perform two ratings. The first is on the relevance and degree of importance of each attribute value for assigning an exemplar which possesses the attribute value to each of the potential categories. The second

is on the degree of unfavourableness of an attribute value possessed by an exemplar in assigning the exemplar to each of the potential categories. The data obtained would index each attribute value's role for forming each of the potential categories. For instance, if an attribute value is rated highly important for category A, it is probably rated highly unfavourable to the contrasting category, i.e. category B. With this set of observed rating on attributes, correlation can then be performed between the predicted and observed indexes. If the correlation is significantly higher than chance, it indicates the subjects formed the constraints and perspective as predicted by the adaptive model.

2) Sorting. Subjects perform the sorting task with the formed perspective. That is, subject will use the index values to assess each exemplar and apply the decision rule in assigning the exemplar to the category. If there is a significantly large proportion of FR sorting, it generally supports the adaptive model as in the two experiments in this project. The predicted and observed sorting results should be compared.

3) Typicality rating. After sorting, subjects rate each exemplar for degree of typicality of the category. Correlation between the predicted and observed typicality rating can be performed. If the correlation is higher than chance, it can be seen as evidence of cognitive system adapting the perspective to data, but in adapting it still tries to maximize the consistency with the perspective. Thus, the adaptive model would be better tested with the three measurements outlined here.

### 6.2.2. Research on the knowledge framework

Our knowledge framework makes two main theoretical claims. One is that the framework has the potential to support development of an approach to stratify knowledge, which is important for incorporating theoretical knowledge in the study of categorization. The second claim is that the framework outlines a plausible account of conceptual change, for it attempts to explain how a low cognitive level conceptual system develops into a conceptual system at a higher level. There are two kinds of tests that should be conducted, both of which should be carried out in knowledge-rich domains instead of with artificial stimulus materials, for only in a knowledge-rich domain, can cognitive levels be clearly demonstrated.

The first type of test involves the four cognitive stages of the framework, namely, expanding the experience base, concept formation, conceptual model building and problem solving with the attained conceptual models. These are within-cognitive stage processes, which are necessary for understanding the mechanisms of conceptual change. However, except concept formation, which this thesis project studied, the cognitive processes of other stages are studied as special areas of cognitive psychology. Therefore, no future research in these areas will be outlined here.

The second type of test is on transitions between cognitive stages and levels. Much of the theoretical claim is actually based on these transitions between the stages. Questions that can be asked here include the following: What conceptual models are needed in order for the cognitive system to experience a set of phenomena? In terms of the framework, this question covers the transition between the conceptual model application stage and the experiencing stage. The hypothesis to be tested is that phenomena at certain cognitive level in a domain are most accessible to people with conceptual models at the next lower level below that to which the phenomena belong. Experiments can be designed to test the perception of a set of phenomena at a given cognitive level in a domain with subjects possessing conceptual models at various cognitive levels.

For the transition between the experiencing stage and conceptualizing stage, the question is: what experience base is needed for the formation of a set of concepts? The hypothesis is that the acquisition of concepts at a certain cognitive level requires a sufficient experience base at the corresponding cognitive level. For the next two transitions from concepts to conceptual model building and from conceptual models to performing cognitive tasks in problem solving, similar questions can be asked and hypotheses can be tested. The point of these tests is not just to see whether certain prerequisites are needed for experiencing, conceptualizing, and conceptual model building, but to see whether it is the prerequisites at the appropriate cognitive level that are needed. If evidence from the experiments shows that cognitive level is an important theoretical construct, then we will have better means for understanding knowledge stratification and for accounting for conceptual change.

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**Appendix I**

Thank you for participating in this research.

I would be grateful if you would fill out the information requested below.

The following information will help me keep track of your booklet while protecting your anonymity:

---

1. Year of birth:

   1 9 __ __

2. Sex:

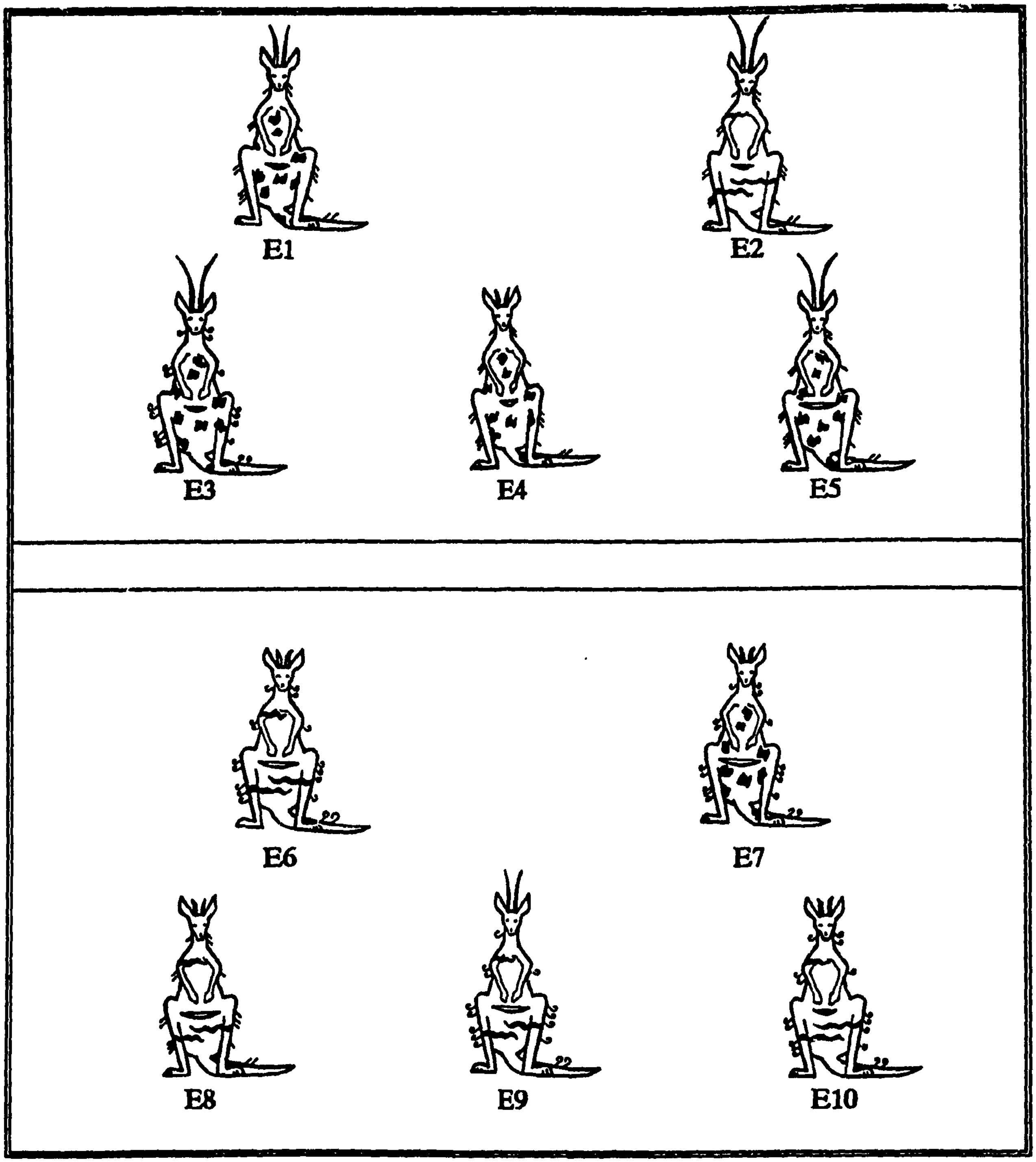
   M ___ F ___

3. Last 4 digits of your telephone number:

   x x x __ __ __ __

---

## Appendix II



## Appendix III

Please read the following carefully and do not hesitate to ask for clarification / explanation if you have any questions. (C.1 Exp.1)

------------------------------------------

**Background:**

A new species of kangaroo was found on a Pacific island. Scientists have been studying the animal for some time and have made some observations. It was found that kangaroos, both male and female, vary in their physical characteristics. Specifically, they vary in four features, i.e., small vs. large pouch, stripes vs. spots in body marks, straight vs. curly hair and long vs. short horns.

**Your task:**

Ten of these kangaroos are shown on the cards. You are to assign the ten kangaroos into two equal-sized groups in a way that seems natural or sensible. Five kangaroos must be assigned to a group. There is no "correct" way of making the assignments. We are interested in what you think is a natural partitioning.

**Procedures:**

In the tables on the next page, write down in the left column the picture number of the kangaroo you have chosen for the group. In the right column, give your reason(s) for assigning the animal to the group. Then, please explain the basis on which you sort the kangaroos into the two groups.

Please explain the basis on which you sort the kangaroos into two groups in **Basis for sorting**. Then in the tables below, write down in the left column the picture number of the kangaroo you have chosen for the group. In the right column, give your reason(s) for assigning the animal to the group.

1) **Sorting:**

| Group One | Reason(s) for assigning the animal to the group |
|---|---|
| # | |
| # | |
| # | |
| # | |
| # | |

| Group Two | Reason(s) for assigning the animal to the group |
|---|---|
| # | |
| # | |
| # | |
| # | |
| # | |

2) **Basis for sorting:**

________________________________________

________________________________________

________________________________________

Thank you very much for your assistance.

## Appendix IV

Please read the following passage carefully and do not hesitate to ask for clarification/ explanation if you have any questions. (C.2 Exp.1)

---

**I. Background:**

A new species of kangaroo was found on a Pacific island. Scientists have been studying the animal for some time and have made some observations. It was found that kangaroos, both male and female, vary in their physical characteristics. Specifically, they vary in four features, i.e., **pouch, body marks, hair** and **horns**, as shown in the drawings. The following is known about each of the features.

1. **Pouch:**
   A kangaroo has either a **small** or **large** pouch.
   Besides carrying babies, in the fall a pouch is also used to carry food gathered from various places to be stored for the winter.

2. **Body marks:**
   A kangaroo has either **spots** or **stripes** on their bodies.
   Spots provide the animal with a good camouflage, which blends the animal with plant leaves in its surroundings.
   Stripes provide a good camouflage for the animal in open areas.

3. **Hair:**
   A kangaroo has either **thin straight** hair or **thick curly** hair. Thin and straight hair helps to dissipate the body heat faster. A kangaroo with thick and curly hair has good protection from the elements (e.g. cold weather and rain) and can stay in the open for an extended period of time.

4. **Horns:**
   A kangaroo has either **long** horns or **short** horns.
   Long horns are better for fighting.
   Short horns are sturdier and therefore a better tool for digging for food in the ground.

**II. Your task:**

There are ten kangaroos shown on the ten cards. You are to assign the ten kangaroos into two equal-sized groups in a way that seemed natural or sensible. Five kangaroos must be assigned to a group. There is no "correct" way of making the assignments. We are interested in what you think is a natural partitioning. Please give the reason(s) for the way you assign the kangaroos into two groups. You can consult the reading passage when making the assignments.

## III. Procedures:

1. **Sorting:** In the tables below, write down in the left column the picture number of the kangaroo you have chosen for the group. In the right column, give your reason(s) for assigning the animal to the group.

| Group One | Reason(s) for assigning the animal to the group |
|---|---|
| # | |
| # | |
| # | |
| # | |
| # | |

| Group Two | Reason(s) for assigning the animal to the group |
|---|---|
| # | |
| # | |
| # | |
| # | |
| # | |

2. **Basis for sorting:** Please explain the basis on which you sort the kangaroos into two groups.

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Thank you for your assistance!

## Appendix V

Please read the following passage carefully and do not hesitate to ask for clarification/ explanation if you have any questions. (C.3 Exp. 1)

---

### I. Background:

A new species of kangaroo was found on a Pacific island. Scientists have been studying the animal for some time and have made some observations. It was found that the kangaroos had, over the years, gradually adopted two types of habitats on the island: the forest area in the lowland and the prairie in the highland.

The two groups of kangaroos have thus been evolving apart from each other in adapting to the conditions of their respective environments. However, they still interbreed. The interbred often share the physical features of both groups to varying degrees. Specifically, they vary in four features:

**1) long horns vs. short horns;**
**2) stripes vs. sports on their bodies;**
**3) straight hair vs. curly hair and**
**4) small pouch vs. large pouch.**

When an interbred young kangaroo leaves its mother's pouch, a decision must be made as to whether the young kangaroo should live in the forest or in the prairie.

### II. Your task:

Now time has come to make decisions for a group of ten interbred young kangaroos. The young kangaroos are shown on the ten cards. You are to assign five young kangaroos to the forest habitat and five to the prairie habitat. Your goal is to make the assignments in such a way as to best help each young kangaroo adapt to its environment.

In the tables on the next page, write down in the left column the picture number of the kangaroo you have chosen for the group. In the right column, give your reason(s) for assigning the animal to the group.

| Forest Group | Reason(s) for assigning the animal to the group |
|---|---|
| # | |
| # | |
| # | |
| # | |
| # | |

| Prairie Group | Reason(s) for assigning the animal to the group |
|---|---|
| # | |
| # | |
| # | |
| # | |
| # | |

Thank you for your assistance!

## Appendix VI

Please read the following passage carefully and do not hesitate to ask for clarification/explanation if you have any questions. (C.4 Exp.1)

-----------------------------------------------------

## I. Background:

### What is known about the kangaroos and their habitats

A new species of kangaroo was found on a Pacific island. Scientists have been studying the animal for some time and have made some observations. It was found that the kangaroos had, over the years, gradually adopted two types of habitats on the island: the forest area in the lowland and the prairie in the highland. The conditions of the two habitats are as follows.

The forest in the lowland

1. **It has warm climate year round and very hot summers.**
2. **It has good food sources which are not widely scattered. This means that in the fall kangaroos do not have to travel a wide area to gather and carry food home for the winter.**
3. **It is a relatively dangerous place. There are large animals that prey on kangaroos.**

The prairie on the highland

1. **It has cold climate and harsh winters.**
2. **The food sources are widely scattered, which means that in the fall kangaroos must travel widely to gather and carry food home for the winter. As there are not many fruit bearing plants in the area, much of the food source consists of roots of plants, which kangaroos must dig into the sandy soil to retrieve.**
3. **There are very few large animals which are dangerous to the kangaroos in the prairie.**

Those living in the forest area are called forest dwellers and those living in the prairie are prairie dwellers. It was also found that kangaroos, both male and female, vary in their physical characteristics. Specifically, they vary in four features, i.e., pouch, body marks, hair and horns, as shown in the drawings. The following is known about each of the features.

1. Pouch:
   A kangaroo has either a small or large pouch.
   Besides carrying babies, in the fall a pouch is also used to carry food

gathered from various places to be stored for the winter.

2. **Body marks:**
A kangaroo has either **spots** or **stripes** on their bodies.
Spots provide the animal with a good camouflage, which blends the animal with plant leaves in its surroundings.
Stripes provide a good camouflage for the animal in open areas.

3. **Hair:**
A kangaroo has either **thin straight** hair or **thick curly** hair.
Thin and straight hair helps to dissipate the body heat faster.
A kangaroo with thick and curly hair has good protection from the elements (e.g. cold weather and rain) and can stay in the open for an extended period of time.

4. **Horns:**
A kangaroo has either **long** horns or **short** horns.
Long horns are better for fighting.
Short horns are sturdier and therefore a better tool for digging for food in the ground.

## II. Your task:

### What decisions must be made

Though the two groups of kangaroos have been evolving apart from each other in adapting to the conditions of their respective environments, they still interbreed. The interbred often share the physical features of both groups to varying degrees. When an interbred young kangaroo leaves its mother's pouch, a decision must be made as to whether the young kangaroo should live in the forest or in the prairie. This is a crucial moment for the young kangaroo because the decision will affect the young kangaroo's chance of survival.

Now time has come to make decisions for a group of **ten** interbred young kangaroos. The young kangaroos are shown on the ten cards. You are to assign five young kangaroos to the forest habitat and five to the prairie habitat. Your goal is to make the assignments in such a way as to ensure the best chance of survival for each kangaroo.

Please use only the information given in the reading passage when making the assignments and do not assume anything not given in the passage. For instance, do not assume that one feature is more important than another.

You can consult the reading passage when making the assignments.

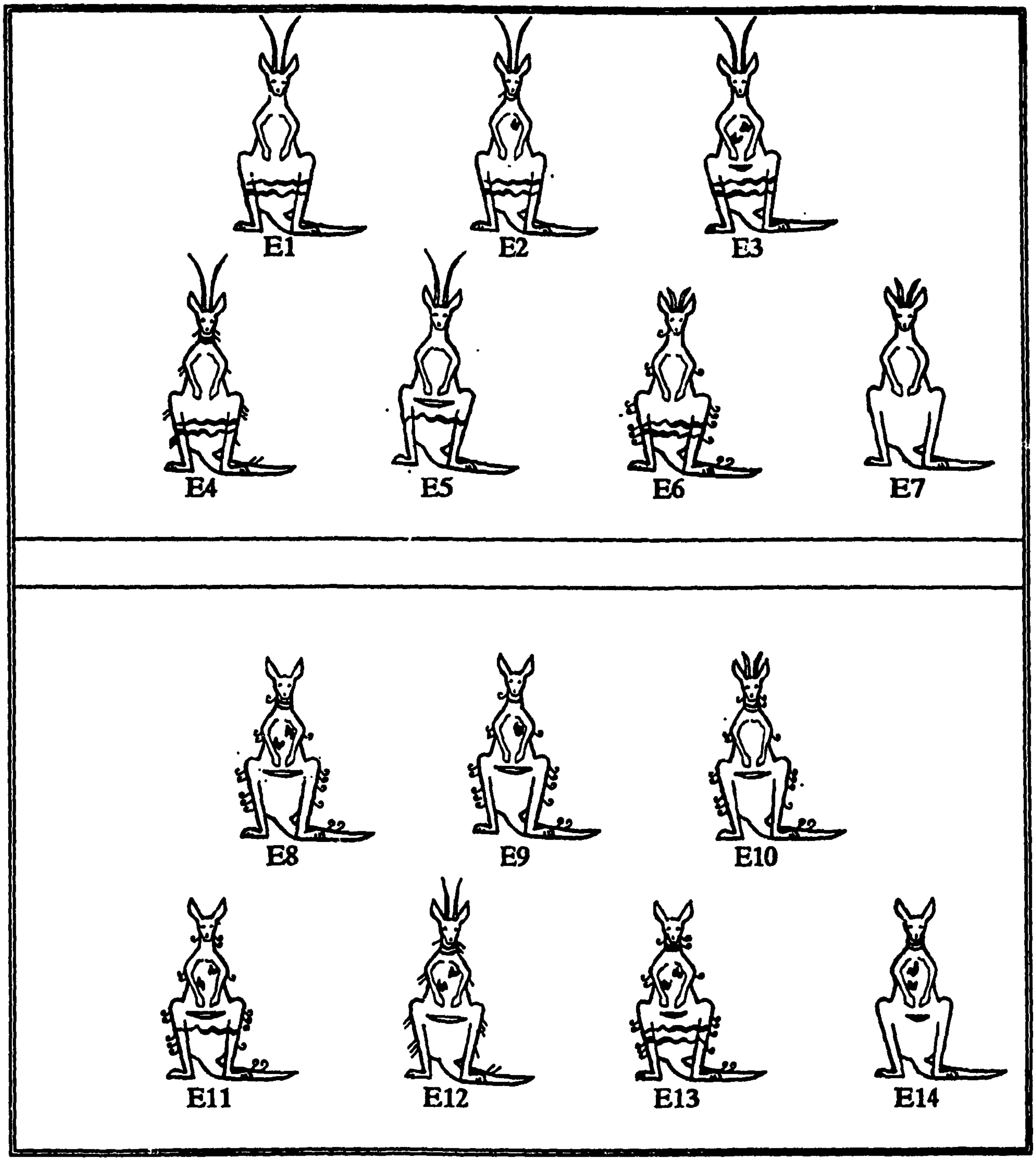
## III. Procedures:

In the tables below, write down in the left column the picture number of the kangaroo you have chosen for the group. In the right column, give your reason(s) for assigning the animal to the group.

| Forest Dwellers | Reason(s) for assigning the animal to the group |
|---|---|
| # | |
| # | |
| # | |
| # | |
| # | |

| Prairie Dwellers | Reason(s) for assigning the animal to the group |
|---|---|
| # | |
| # | |
| # | |
| # | |
| # | |

Appendix VII



## Appendix VIII

Please read the instructions carefully and do not hesitate to ask for clarification or explanation if you have any questions. (C.1 Exp. 2)

### I. About the Kangaroos:

A new species of kangaroo was found on a Pacific island. Scientists have been studying the animal for some time and have made some observations. It was found that kangaroos, both male and female, vary in their physical characteristics. Specifically, they vary in the following six features. A kangaroo can have

a large pouch, small pouch or no pouch;
two stripes, one strip or no strip;
curly hair, straight hair or no hair;
two upper body spots, one upper body spots or no spot;
long horns, short horns or no horns;
two neck rings, one neck ring or no ring.

Fourteen of these kangaroos are shown on the cards. You are to assign the fourteen kangaroos into two equal-sized groups in a way that seemed natural or sensible. Seven kangaroos must be assigned to a group. There is no "correct" way of making the assignments. We are interested in what you think is a natural partitioning.

### II(a). Sorting:

1. Assign 7 kangaroos for each group by writing down, in column 1, the card number of the selected kangaroo at the back of the cards.

2. State the reason(s), in column 2, why it is assigned to the group.

3. Rank order the 7 kangaroos in each group, in column 3, from 1 to 7. 1 stands for the best or most typical member and 7 stands for the worst of least typical member of the group.

4. Please rate your level of confidence in assigning each kangaroo to the two groups from 1 to 7. 1 stands for "with most confidence" and 7 stands for "with least confidence".

| Group One | Reason(s) | Rank Order | Confidence Rating |
|---|---|---|---|
| # | | | |
| # | | | |
| # | | | |
| # | | | |
| # | | | |
| # | | | |
| # | | | |

| Group Two | Reason(s) | Rank Order | Confidence Rating |
|---|---|---|---|
| # | | | |
| # | | | |
| # | | | |
| # | | | |
| # | | | |
| # | | | |
| # | | | |

**II(b). Please describe the strategy or strategies you used in sorting the kangaroos into two groups. You can also briefly describe the decision process in assigning some individual kangaroos.**

________________________________________

________________________________________

________________________________________

________________________________________

**III. Importance Rating:**

The table on the next page is designed for you to weigh the importance of each feature in your decision to assign the kangaroos to the two groups.

First, decide whether a particular feature belongs to Group One or Group Two or neither. If it belongs to neither, mark an "X" in the column "0" for the feature. If it is considered as a feature for one of the two groups, then decide the feature's importance weight. A 3-point scale is used for importance weight. 1 stands for "a relevant feature for the group". 2 stands for "a quite important feature for the group" and 3 "a very important feature for the group". For instance, you might consider a particular feature as very important for Group One and give it 3 points in weight by marking an "X" in the column "3" under Group One.

| | | Group One | | | | Group Two | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 0 | 1 | 2 | 3 |
| Horns | No Horn | | | | | | | |
| | Short | | | | | | | |
| | Long | | | | | | | |
| Stripes | 0 | | | | | | | |
| | 1 | | | | | | | |
| | 2 | | | | | | | |
| Spots | 0 | | | | | | | |
| | 1 | | | | | | | |
| | 2 | | | | | | | |
| Hair | No Hair | | | | | | | |
| | Straight | | | | | | | |
| | Curly | | | | | | | |
| Pouch | No Pouch | | | | | | | |
| | Small | | | | | | | |
| | Large | | | | | | | |
| Rings | 0 | | | | | | | |
| | 1 | | | | | | | |
| | 2 | | | | | | | |

## IV. Unfavourableness Rating:

On the next page, the rating is designed for you to identify and rate those features which "pull away" an animal from a group.

First, decide whether a feature is unfavourable to assigning an animal to one of the two groups. If it is not, mark an "X" in the column "0" for the feature. If it is considered unfavourable to either of the two groups, rate the degree of unfavourableness. A 3-point scale is used for the rating. 1 stands for "unfavourable to the group". 2 stands for "quite unfavourable to the group" and 3 "very unfavourable to the group". For example, if you consider a particular feature very unfavourable to Group Two, give it 3 points by marking an "X" in column "3" under Group Two.

| | | Group One | | Group Two |
|---|---|---|---|---|
| | | 1 2 3 | 0 | 1 2 3 |
| Horns | No Horn | | | |
| | Short | | | |
| | Long | | | |
| Stripes | 0 | | | |
| | 1 | | | |
| | 2 | | | |
| Spots | 0 | | | |
| | 1 | | | |
| | 2 | | | |
| Hair | No Hair | | | |
| | Straight | | | |
| | Curly | | | |
| Pouch | No Pouch | | | |
| | Small | | | |
| | Large | | | |
| Rings | 0 | | | |
| | 1 | | | |
| | 2 | | | |

## Appendix IX

Please read the following passage carefully and do not hesitate to ask for clarification or explanation if you have any questions. (C.2 Exp.2)

### I. About the Kangaroos:

#### What is known about the kangaroos

A new species of kangaroo was found on a Pacific island. Scientists have been studying the animal for some time and have made some observations. It was found that kangaroos live in groups. In each group, adult kangaroos, both male and female, are always found to vary in the six features as shown in the drawings. The following is known about each of the features.

1. Pouch:
   Kangaroos vary by having no pouch, a small pouch or large pouch. A pouch is useful (in addition to carrying babies in the spring) for carrying food gathered from various places in the fall to be stored for the winter.

2. Stripes:
   Stripes indicate a kangaroo's rate of metabolism, which affects the temperament of the animal. It is found that the more stripes a kangaroo has, the more it becomes irritable and aggressive. When a kangaroo has no stripe, it is very active, energetic and hard working.

3. Hair:
   A kangaroo sheds its hair every third summer. In the following fall, it grows thin and straight hair. The hair will grow thick and curly a year later.
   A kangaroo without enough hair may get sick if exposed to cold and harsh weather. A kangaroo with thick and curly hair has good protection from the weather and can stay in the open for an extended period of time.

4. Horns:
   A kangaroo sheds its horns three times in a life time. When a kangaroo sheds the horns, it has no horns. It takes about a year for the animal to grow short horns, which will grow to the full length in two years. Horns are the most important weapon. The longer the horns, the more advantage a kangaroo has in fighting.

5. Upper body spots:
A kangaroo group is usually composed of several families. The number of spots indicate family lineage of the kangaroos. That is, kangaroos with the same number of upper body spots are from the same family.

6. Rings:
The rings on the neck indicate the patterns of courting behaviour. The more rings, the more active a kangaroo is in courting and looking for mates. However, at the present, very little is known about other social behaviour of the kangaroos.

**What the kangaroos must do in the fall**

There are no predators on the island. Animals do not kill for food. However, survival is a constant struggle on the island because of the scarcity of food. Kangaroos get into a fight only when defending their stored food.

The food source is widely scattered. As they cannot find large quantities of food in any one place, kangaroos travel around the island in the spring and summer. However, in the fall, a kangaroo group must settle down and build a den in which to store food for the winter. Thus in the fall, all adult kangaroos are engaged in two tasks: to travel and gather food and to guard the stored food. Those who travel to look for food are gatherers and those who stay behind and guard the stored food are guards. As kangaroos vary in their temperamental fitness, carrying capacity and protective ability from cold and rain, some are better suited for the task of gatherers than others. As they also vary in their ability to fight and guard the stored food, some are better suited for the task of guards than others.

The ecological system on the island is such that the survival of the group depends on an optimal assignment of the kangaroos to the two tasks. That is, optimal assignment helps them avoid either being unable to gather enough food for the winter or being unable to protect the stored food.

Here we have a typical group of 14 kangaroos which are shown on the cards. Time has come for assigning the kangaroos to the two task groups. We are interested in how you would assign the kangaroos to be gatherers and guards in such a way as to ensure the group the best chance to survive the winter.

Please use only the information given in the reading passage in making the assignments and do not assume anything not given in the passage.

## II(a). Sorting

(Table for the guards group is on the next page.)

1. Assign 7 kangaroos to each of the two task groups by writing down, in column 1, the card number of the selected kangaroo at the back of the cards.

2. State the reason(s), in column 2, why it is assigned to the gatherer or guard task group.

3. Rank order the 7 kangaroos in each task group, in column 3, from 1 to 7. 1 stands for the best or most typical member and 7 stands for the worst of least typical member of the task group.

4. Please rate your level of confidence in assigning each kangaroo to the two task groups from 1 to 7. 1 stands for "with most confidence" and 7 stands for "with least confidence".

| Gatherers | Reason(s) | Rank Order | Confidence Rating |
|---|---|---|---|
| # | | | |
| # | | | |
| # | | | |
| # | | | |
| # | | | |
| # | | | |
| # | | | |

| Guards | Reason(s) | Rank Order | Confidence Rating |
|---|---|---|---|
| # | | | |
| # | | | |
| # | | | |
| # | | | |
| # | | | |
| # | | | |
| # | | | |

**II(b). Please describe the strategy or strategies you used in sorting the kangaroos into two groups. You can also briefly describe the decision process in assigning some individual kangaroos.**

________________________________________

________________________________________

________________________________________

________________________________________

**III. Importance Rating:**

The table on the next page is designed for you to weigh the importance of each feature in your decision to assign the kangaroos to the two task groups.

First, decide whether a particular feature is a gatherer's feature or guard's feature or neither. If it is neither, mark an "X" in the column "0" for the feature. If it is considered as a feature for one of the two task groups, then decide the feature's importance weight. A 3-point scale is used for importance weight. 1 stands for "a relevant feature for the task group". 2 stands for "a quite important feature for the task group" and 3 "a very important feature for the task group". For instance, you might consider a particular feature as a very important guard's feature and give it 3 points in weight by marking an "X" in the column "3" under Guard.

| | | Gatherer | | | | Guard | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 0 | 1 | 2 | 3 |
| Horns | No Horn | | | | | | | |
| | Short | | | | | | | |
| | Long | | | | | | | |
| Stripes | 0 | | | | | | | |
| | 1 | | | | | | | |
| | 2 | | | | | | | |
| Spots | 0 | | | | | | | |
| | 1 | | | | | | | |
| | 2 | | | | | | | |
| Hair | No Hair | | | | | | | |
| | Straight | | | | | | | |
| | Curly | | | | | | | |
| Pouch | No Pouch | | | | | | | |
| | Small | | | | | | | |
| | Large | | | | | | | |
| Rings | 0 | | | | | | | |
| | 1 | | | | | | | |
| | 2 | | | | | | | |

## IV. Unfavourableness Rating:

On the next page, the rating is designed for you to identify and rate those features which "pull away" an animal from a task group.

First, decide whether a feature is unfavourable to assigning an animal to one of the two task groups. If it is not, mark an "X" in the column "0" for the feature. If it is considered unfavourable to either of the two task groups, rate the degree of unfavourableness. A 3-point scale is used for the rating. 1 stands for "unfavourable to the task group". 2 stands for "quite unfavourable to the task group" and 3 "very unfavourable to the task group". For example, if you consider a particular feature very unfavourable to the gatherer's task, give it 3 points by marking an "X" in column "3" under Gatherer.

| | | Gatherer | | | | Guard | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 0 | 1 | 2 | 3 |
| Horns | No Horn | | | | | | | |
| | Short | | | | | | | |
| | Long | | | | | | | |
| Stripes | 0 | | | | | | | |
| | 1 | | | | | | | |
| | 2 | | | | | | | |
| Spots | 0 | | | | | | | |
| | 1 | | | | | | | |
| | 2 | | | | | | | |
| Hair | No Hair | | | | | | | |
| | Straight | | | | | | | |
| | Curly | | | | | | | |
| Pouch | No Pouch | | | | | | | |
| | Small | | | | | | | |
| | Large | | | | | | | |
| Rings | 0 | | | | | | | |
| | 1 | | | | | | | |
| | 2 | | | | | | | |