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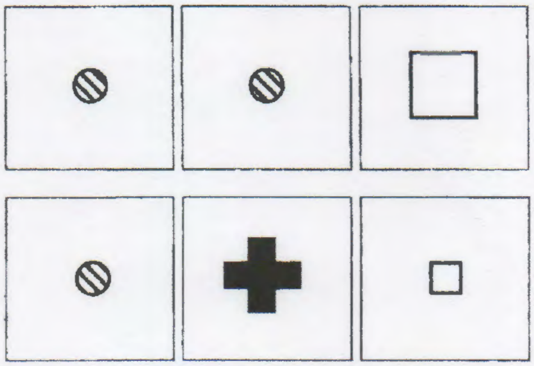
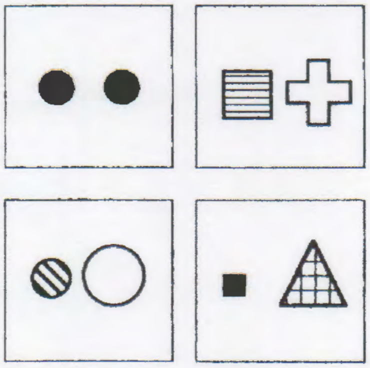


SPECIAL ISSUE

Models in
Cognitive Behavioural
Pharmacology



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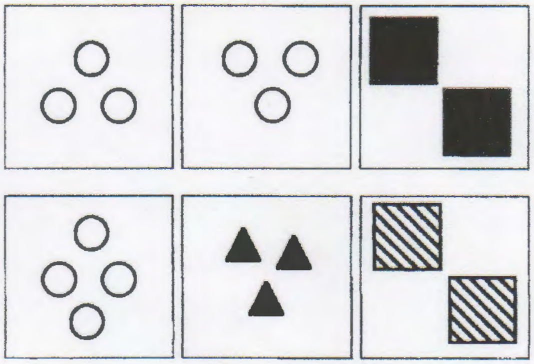

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Editorial

This issue of *Cognitive Brain Research* contains a series of reviews covering the topic of *Models in Cognitive Behavioural Pharmacology*. They emphasise the need for a critical examination of the strengths, but also the limitations of the methods used for the experimental analysis of cognitive behaviour in animals. This exercise is of high relevance, since there is a bewildering range of behavioural methods available to researchers, much experimental data are controversial, and extrapolation of animal data to humans is far from ideal. Numerous factors could explain this dilemma. These include poor experimental design, the uncritical application of models measuring different aspects of cognitive function and, perhaps, a tendency to draw oversimplistic conclusions. Having delineated this pessimistic view, the question arises 'should animal models be abandoned?' Clearly, this would be counterproductive. The analytical power of valid animal models is essential for understanding the psychopharmacological mechanisms of drug actions, the behavioural effects of neural damage and for identification of new therapeutic strategies of psychiatric disorders.

In this special issue, lessons from different disciplines, ranging from cognitive psychology to neurochemistry and electrophysiology, are taken into account. Also, significant attention is given to understanding the experimental parameters which can influence the outcome of studies. In the first article, Roger Thomas describes how the various animal models of cognitive function relate to each other, thereby providing a framework in which most of the following papers can be discussed. This is followed by articles providing detailed discussions of advantages and disadvantages of different behavioural methods used for the assessment of these cognitive abilities. From these articles it becomes evident that non-specific factors can confound the outcome of studies, and the importance of these factors is stressed in subsequent contributions. The comparability of data from different species is then discussed. Questions such as 'What cognitive abilities are common to all species?' and 'What procedures are available to measure these comparable abilities?' are considered. Finally, the need for greater integration of data from behavioural, neurochemical and electrophysiological studies to enable better understanding of behavioural pharmacological mechanisms is discussed.

Having to deal with a broad field, such as the assessment of cognitive behaviour in animals, it becomes obvious that the special issue must fail in any attempt to be comprehensive. However, despite its many gaps we hope that this issue of *Cognitive Brain Research* will promote understanding of the factors that confound data interpretation, provide impetus for essential fundamental research and ultimately have some guiding influence upon the application of animal models of human cognitive function in future.

Thomas Steckler and Glen D D'Mello

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Investigating cognitive abilities in animals: unrealized potential

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Abstract

Cognitive abilities related to learning ability and intelligence involve 8 levels of fundamental processes. Any and all of such cognitive abilities reduce to these 8 levels or to combinations of them. The 8 levels are hierarchical because lower levels, generally, are prerequisites for higher levels. An animal's general cognitive ability is determined by how many of the fundamental processes it can use. Although the processes are hierarchical, an animal will use all processes available to it in serial or in parallel as the situation requires. A perusal of contemporary journals' contents will show that behavioral neuroscientists, including behavioral pharmacologists, rarely study cognitive abilities that require the use of processes at the highest 4 levels. Yet, all vertebrates may be capable of using level-5 processes, and several avian and mammalian species have been shown to use level-6 processes. The use of level-7 processes has been shown in non-human primates and likely can be shown in non-primate species, too. The present article provides an overview of the basic cognitive processes as well as types of tasks that might be used to investigate the neural correlates or substrates of higher cognitive processes in animals. Unless and until better measures of cognitive ability are used, a vast potential for research will be unrealized.

Keywords: Animal cognition; Animal learning; Cognition; Comparative cognition; Cognitive process; Intelligence; Learning

1. Introduction

Cognition and cognitive ability are terms whose meanings are usefully vague and which must be defined in each context that they are used. In the present context, cognitive ability is synonymous with learning ability, and learning ability is a fundamental and defining aspect of intelligence; see Thomas [13] for a relevant literature review. The present article describes a general approach to investigations of cognitive ability that can be used with any species. As will be shown, the higher-order cognitive abilities that could be investigated in animals have been largely overlooked or ignored by behavioral neuroscientists, including behavioral pharmacologists.

Cognitive abilities correspond to cognitive processes that are hierarchical. There are 8 levels of cognitive processes (see Fig. 1). Any and all measures of cognitive ability either involve 1 of these 8 levels or combinations of them. The processes are hierarchical, because in general, lower-level processes are prerequisites for higher-level processes. However, being hierarchical does not mean that an animal will use the processes serially. To the contrary, it is likely that an animal will use all the processes within its repertoire as needed whether that be to use them serially or in parallel.

A fundamental point is that most investigations using pharmacological manipulation of cognitive processes or using pharmacological methods to investigate cognitive processes have used tasks that have involved only the lower 4 levels of cognitive abilities. The 4 upper levels of cognitive abilities remain largely uninvestigated in the context of behavioral pharmacology. After discussing the hierarchy of cognitive processes, a brief overview near the end of this article will be provided to show where some of the frequently used behavioral paradigms in behavioral pharmacology fit into the hierarchy of cognitive abilities.

It may be noted that some species of fish, reptiles, birds, and mammals have performed successfully at level 5 (amphibians appear not to have been tested), and many more species likely have these abilities. Several species of birds and mammals have performed successfully on some types of concepts at level 6, and some non-human primates have performed successfully at level 7. It is believed that other species are likely to be successful at levels 6 and 7 as well. There appear to have been no attempts to investigate whether a non-human animal can perform at level 8.

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2. Learning/intelligence/cognitive processes hierarchy

The original purpose for constructing this hierarchy was to provide indexes of comparative intelligence to be used in correlational studies with indexes of brain evolution. As indicated in Fig. 1's title, it was assumed that learning ability defines intelligence; see literature reviewed by Thomas [13]. It is also assumed that learning ability is a fundamental cognitive ability. Intelligence, learning ability, and cognitive ability, as the latter relates to learning ability, are used interchangeably here.

As can be seen in Fig. 1, the most basic, complementary processes, Habituation and Sensitization, comprise level 1. In succession, level 2 is Signal Learning (Pavlovian conditioning), level 3 is Stimulus–Response Learning (simple operant learning), level 4 is Chaining (learning a series of level 3, S-R operant units), and level 5 is Concurrent Discrimination Learning (learning level 3, S-R operant units in parallel). Levels 1–5 differ fundamentally from levels 6–8 in that levels 1–5 involve associative processes where repetition of stimulus and reinforcement associations is the norm and where learning can be done by rote. Levels 6–8 involve concept learning where an essential defining criterion is that the discriminanda must be new on critical test trials (see discussion below in the section, Essential Evidence to Show Use of a Concept). This condition is necessary if one is to conclude that the animal responded to the discriminanda as members of a conceptual class rather than as rote-learned associations between particular discriminanda and reinforcers.

Learning-Intelligence Hierarchy

LEVEL	CATEGORY
8	**Relational Concepts II**: Using Class Concepts in Biconditional Relationships
7	**Relational Concepts I**: Using Class Concepts in Conjunctive, Disjunctive, or Conditional Relationships
6	**Absolute and Relative Class Concepts**
5	**Concurrent Discrimination Learning**: Learning S-R Units in Parallel
4	**Chaining**: Learning S-R Units in Series
3	**Stimulus-Response Learning**: Simple Operant Conditioning
2	**Signal Learning**: Pavlovian Conditioning
1	**Habituation and Sensitization**

This hierarchy was synthesized by Thomas (1980, 1987) and was based extensively on Gagne (1970) and Bourne (1970).

Fig. 1. The hierarchy of basic cognitive processes associated with learning ability and intelligence.

As noted, the learning processes are hierarchical, because lower-level processes are prerequisites for higher-level processes [3,13]. Where available, empirical data also confirm the hierarchy. The assumption that Chaining is prerequisite to Concurrent Discrimination Learning is questionable because they may be parallel processes. Their relative placement here follows Gagne's [3] precedent.

In any case, most attention here will be on levels 6–8 which clearly involve prerequisite ordering, and level 6 is clearly of a higher order than level 5. As noted, although the processes are hierarchical, an animal will likely use all the processes of which it is capable, concurrently, in serial and in parallel. For example, an animal that can perform a concept learning task at level 6 will also use classical and instrumental conditioning (levels 2 and 3) because they are inherently part of what an animal must do to perform a concept learning task.

The hierarchy is exhaustive; i.e. any specific measure of learning or cognitive ability used in the past, present, and future will involve one of the basic processes in the hierarchy or combinations of the basic processes. The upper limit of an animal's general cognitive ability is determined by the highest level among the basic processes of which it is capable. For example, an animal that can use basic processes from levels 1–6 in the hierarchy is assumed to have more cognitive ability than an animal that can use processes only from levels 1–5.

Data will be cited that indicate that at least some species from all the vertebrate classes are capable of using the learning processes required at level 5, with the possible exception of amphibians which appear not to have been tested. Amphibians have been shown to be capable of types of learning that involve level-3 processing. Several species of birds and mammals have been shown to be capable of absolute class concept learning (level 6), and no doubt many other species of birds and mammals have similar capabilities. However, there is reason to question whether any non-primate animal has been shown unambiguously to be capable of *relative* class concept learning (also at level 6), although it is reasonable to believe that non-primate species, including rats, may have this capability. Absolute and relative class concepts are discussed further below.

When one studies higher cognitive processes in animals for whatever purpose, the emphasis should be on the *processes* involved rather than on specific tasks, apparatuses, etc. By emphasizing the investigation of processes rather than the use of specific tasks, task variables can be adapted to be optimal for the animal. For each species to be studied, the investigator can use discriminanda, responses, incentives, and environmental conditions (e.g. ambient illumination, humidity, temperature, time of day) that are optimal for that species' performances. In that way, one can lessen the chances of confounding an animal's potential to perform successfully (ability) with its actual performance which may underestimate its ability.

For example, discrimination learning tasks used with monkeys are typically constructed by using visual discriminanda, by requiring responses where the monkey manipulates the objects by hand, and by using bits of fruit as the incentives. Since rats appear to have better olfactory than visual capacity [7], more appropriate discrimination learning tasks for rats should be based on olfactory cues rather than visual cues.

2.1. *Level 5: Concurrent Discrimination Learning*

Before considering level 5, it will be useful to contrast it with level 4, Chaining. Chaining tests how many Stimulus–Response Learning units (level 3) can be learned serially. A S-R unit would be any discrete unit of information to be acquired. For example, each choice point in a multiple-T maze would be a unit to be learned and chained to the other units. Comparative data are not readily available, but even experimentally brain-damaged rats have been shown to learn 18-unit mazes.

Level-5 tests how many S-R units can be learned in parallel. When testing an animal at level 5, it is given a set of *n* number of discrimination problems (triangle vs. square, diamond vs. cross, circle vs. pentagon, etc.). The measure of ability at level 5 is how many problems the animal can learn to discriminate when the different problems are presented in random order. Some animals, such as the horse and the elephant, learned as many as 20 problems concurrently, and the rat learned 8 problems concurrently [9]. Rensch [9] cited data that show that some species of fish, reptiles, birds, and mammals are capable of some degree of Concurrent Discrimination Learning. Amphibians apparently have not been tested at level 5.

Before considering level 6, it needs to be iterated that levels 6–8 involve concept learning. Specifically, level 6 involves learning class concepts and levels 7 and 8 involve using class concepts in conjunctive, disjunctive, conditional, and biconditional relationships. Before addressing class and relational concepts in detail, it will be useful first to discuss the kinds of evidence and conditions-to-be-met that are necessary in order to show that concept learning has occurred.

2.1.1. *Essential evidence to show use of a concept*

The essential evidence that an animal has used a class concept is whether it can respond correctly to *new* exemplars; i.e. exemplars not experienced previously. The optimal procedure is to use *trial-unique* discriminanda, i.e., an individual discriminandum is never used twice. Alternatively, one might repeat presentations of the discriminanda but limit the evidence for use of the concept to the *first trials* with new exemplars. The trial-unique or first-trial-only requirements are essential. Otherwise, it is possible that the animal simply learns by rote which particular discriminanda are associated with reinforcers. There have been numerous claims of class concept use by animals where the investigations do not withstand the rigor of this criticism.

2.1.2. *Confounds to be avoided*

There are several other methodological conditions to be met or confounds to be avoided in order to show that an animal has responded conceptually. Thomas and Lorden [17] previously discussed the principal ones in conjunction with the conditions necessary to show conceptual numerousness judgments by animals. However, similar methodological considerations apply to other kinds of conceptual judgments.

The following enumerated items summarize some of the major confounds to be avoided and other essential considerations when the goal is to be able to show evidence for concept learning.

1. Inadvertent experimenter cueing of animals must be avoided; this is especially critical when the experimenter works in direct visual and, perhaps, other sensory contact with the subject. Many investigations involve the experimenter and the animal working in direct contact in a one-to-one relationship. Such investigations should be examined carefully and critically for the possibility of inadvertent cueing.

2. Closely related to item 1, *replicability* in science is an essential condition. Replication of such one-to-one, experimenter-subject investigations as described in item 1 must be done with other experimenters and other animal subjects before the findings can be considered to be reliable, valid, and credible. Even filmed or videotaped records of the experimenter-subject interactions are not sufficient. Recall the famous investigation of Clever Hans the 'counting horse.' Skilled, skeptical observers were unable to detect the cues that Hans' owner, Mr. von Osten, emitted, and it is relevant to note that Mr. von Osten himself was apparently unaware of his cueing.

3. The odor of food reinforcers must not be uniquely associated with the correct item that the subject should choose. Numerous studies have violated this condition.

4. Cues irrelevant to the concept of interest but which might be uniquely associated with the discriminanda that comprise the correct choices must be avoided. Examples of such confounding cues are cumulative area, volume, etc., associated with the entities in a number judgment task or brightness cues in a task based on pattern discrimination.

5. The possibility of memorizing specific patterns or specific properties of objects must be precluded, and it must be realized that such memorization might occur following a single stimulus presentation. Therefore, when concept learning is based on evidence where transfer tests are important and the transfer tests involve re-presenting stimulus items, correct responses might result from having memorized features of those specific items as opposed to

responding to the items on a conceptual basis. This is particularly applicable in trying to distinguish between a learning set formation interpretation as opposed to an interpretation that is based on responding to stimuli as members of a conceptual class. Because learning set has been so important in the history of animal research associated with so-called 'higher-order' learning, it will be addressed separately in a section near the end of this article.

6. Responding based on stimulus generalization must be precluded or must be distinguished from responding on a conceptual basis. Stimulus generalization involves a failure to discriminate, and a seemingly 'new' item might be chosen correctly because the subject failed to discriminate it from an item previously seen rather than responding to the new item as an new exemplar of a conceptual class (see 5 above).

With respect to the essential evidence needed to show class concept use and in view of what was said earlier about using trial-unique and first-trial-only data, it is pertinent to note that when studying relative class concepts (discussed below) one can reuse stimulus objects provided there is no consistent relationship between the object and the reinforcement contingencies. For example, with the oddity concept task, a given object, A, might be odd when presented with two identical objects, B, (ABB) or one might use two object A's and present them together with a new object, C, (ACA) in which case, C is odd. Later, A might be used again with two new objects, D, (ADD) in which case the A is again odd. Object A must not be consistently odd or consistently non-odd, or the subject will learn merely to choose or avoid object A according to its relationship with reinforcement.

2.2. *Level 6: Class Concept Learning*

If one can learn absolute class concepts at level 6, then the number of concurrent discriminations that one can make is virtually unlimited, and the use of level-5 processes is inconsequential. For example, there are hundreds of individual trees that are discriminable and there are hundreds of individual birds that are discriminable. An animal that can conceptualize the categories 'tree' and 'bird' can discriminate an unlimited number of trees vs. birds or trees vs. anything-not-a-tree or birds vs. anything-not-a-bird, etc.

2.2.1. *Absolute and relative class concept learning*

The distinction between absolute and relative class concepts is a simple, operational one, but one that may have profound implications in terms of the cognitive ability of different species. With exemplars of absolute class concepts, the features that determine an object's class membership are inherent in each object that manifests the concept. For example, the defining features of a tree are inherent in each tree. The subject need not compare the stimulus object to other stimulus objects to recognize its class membership. With exemplars of relative class concepts, the defining features are not inherent in the objects which manifest the concept but are relative among the objects, such as which object is odd, which is larger, which set of objects manifests fewer, and so on. Operationally, the subject must *compare* the stimulus objects to determine which one manifests the concept.

2.2.2. *Oddity: most-used relative class concept*

The oddity task has been used more than any other task to assess whether animals can use relative class concepts see [8,11,16,18]. Several species of primates are capable of learning the oddity concept under properly controlled conditions (e.g. using trial-unique discriminanda) and there are numerous reports that pigeons and a few reports that rats are capable of learning the oddity concept. However, the present author has yet to find a rat or pigeon study that can withstand rigorous examination, either because trial-unique discriminanda or first-trial data were not used or because other essential methodological conditions enumerated earlier were not met; see also Thomas and Lorden [17] and Thomas [14].

There appear to be no studies using non-primate animals and purporting to show the use of relative class concepts that can withstand rigorous examination, although Langworthy and Jennings' [6] investigation of rats' use of the oddity concept came close. If a rigorous and reliable procedure to show rat oddity learning could be developed, and it is reasonable that one can, it could become a useful tool in behavioral pharmacologists' and other neuroscientists' armamentariums of cognitive tasks.

2.2.3. *Olfactory oddity training in rats*

Because the olfactory oddity problem may have the best potential for success with rats, it will be useful to consider the lessons of the two previous studies of which I am aware, namely, those of Langworthy and Jennings [6] and Thomas and Noble [18]. Langworthy and Jennings gave rats a series of 30 olfactory oddity problems (using ping pong balls saturated with food flavoring odors as discriminanda), each one to a criterion of 16 correct in 20 successive trials. Based on 11 rats being tested and examining only the first trial in each of the last 5 problems, the rats were correct on 69% of the total of 55 first trials (11 rats × 5 problems). This is significantly better than chance suggesting that rats learned the oddity concept. However, a criticism of Langworthy and Jennings' study is that the food reinforcers were available only under the odd ping pong ball. The rat might have been able to smell the food and choose the odd ball by smelling the food beneath it.

Thomas and Noble [18] controlled against the use of the food reinforcer odor cues by placing an equal amount of food beneath each of the balls. Our rats got a new problem after 5 trials, and we gave a total of 300 problems. Our rats never performed better than chance on trial 1, although they did on trial 2. The significance of successful trial-2 performances will be discussed later in the section, Learning Set Formation. It is important here to iterate that one cannot conclude that the rat has learned the oddity concept when it fails to choose the odd object on the first trials. Additional studies are needed to determine whether training with control of food reinforcer cues combined with Langworthy and Jennings' [6] more extensive training on each oddity problem will result in a successful demonstration of oddity concept learning in the rat.

2.2.4. Visual oddity and sameness-difference tasks

Visual oddity and sameness-difference tasks have exceptional potential for development in behavioral pharmacological and other neuroscience research, especially with primates and other visually oriented animals. It is also possible to systematically construct oddity and sameness-difference tasks to form several levels of relative ease or difficulty. It will be useful to examine such tasks with the aid of Fig. 2. While Fig. 2 depicts two-dimensional pattern discriminanda, often investigators use miscellaneous objects, such as toys or other small plastic or wooden items, as discriminanda. These can be used directly or photographed.

Emphasizing initially the 2 oddity problems depicted in the top third of Fig. 2, please note that with manipulations of color, form, and size, 'easy' and 'difficult' oddity problems can be constructed. Monkey [16] and human [11] studies have validated these characterizations for problems comparable to those depicted as being relatively easy or difficult. As can be seen, the easy problem employs 2 identical non-odd items and 1 odd item that differs from

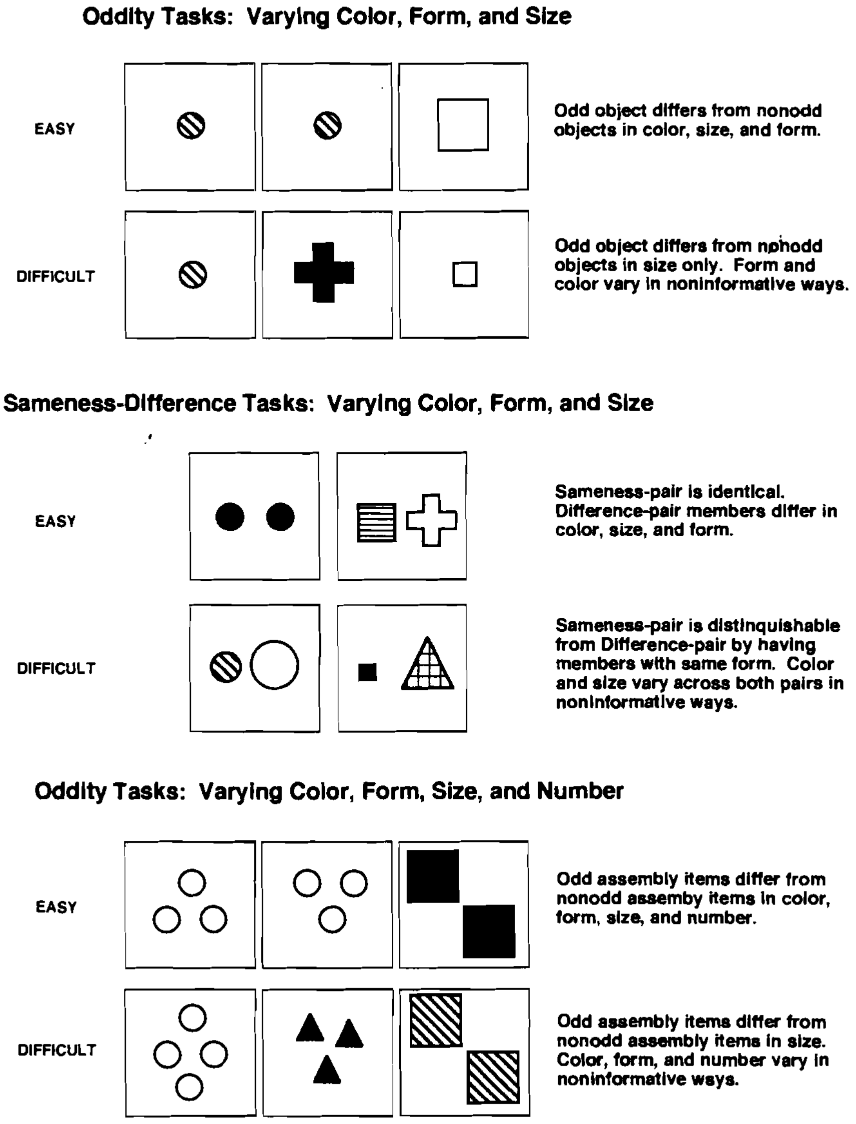

Fig. 2. Examples to illustrate how oddity and sameness-difference problems which manifest absolute and relative class concepts might be constructed. Examples also illustrate problems at several levels of relative difficulty. See text for further explication. Acknowledgment is due to Susan Meier for preparing the figure.

the non-odd items in color, form, and size. In the more difficult example as depicted, the only relevant cue that distinguishes the odd item from the non-odd items is size; all 3 items vary in color and shape, so those cues are non-informative in terms of differentiating the odd and the non-odd items. Two other terms that describe the non-informative cues and that have been used in the literature are that such cues are ambiguous or are distracters. Note that while size provided the relevant cue in the example shown for the difficult oddity problem in the upper third of Fig. 2, the relevant cue might have been color in which case size and form would be non-informative or the relevant cue might have been form in which case color and size are non-informative. Finally with respect to the 2 oddity problems in the upper third of Fig. 2, it may be noted that 4 intermediate levels of problems in terms of relative ease or difficulty can be constructed between the easy and difficult problems depicted, given a total of 6 levels of relative ease or difficulty. See Steirn and Thomas [11] for a figure that illustrates all 6 levels as well as further explication of how the 6 levels are constructed.

The 2 problems depicted in the middle third of Fig. 2 involve a related yet different paradigm, the sameness-difference task. Like the oddity task, 6 levels of problems in terms of relative ease or difficulty can be constructed; all 6 levels may be seen and their construction is explained in Steirn and Thomas [11]. A significant cognitive difference between the sameness-difference concept task and the oddity concept task is that the oddity task involves only relative class conceptual judgments, whereas the first 3 levels of the sameness-differences task, where the sameness-pair contains identical members, involves an absolute class concept. That is, viewing the sameness-pair as manifesting one conceptual entity (sameness) and the difference-pair as manifesting another conceptual entity (difference), one need not compare the two entities to affirm which one manifests sameness or difference; this assumes that only sameness or only difference is correct on a given trial. However, the more difficult sameness-difference problem depicted in the middle third of Fig. 2 requires that the two entities must be compared in order to determine which pair has members that are more similar or more different than the other pair; it may be noted that the 2 levels not depicted but closest in construction to the difficult problem depicted also require such comparisons; see Steirn and Thomas [11].

Finally, the oddity tasks depicted in the lower third of Fig. 2 indicate how even more levels of difficulty can be constructed when a fourth variable, number, is added to the other three variables, color, form and size. Other variables can be manipulated (e.g. varying the color of the background on which the stimuli appear) that would allow for even more levels of problem difficulty to be constructed. A reason to have several potential levels of difficulty is to be able to construct problems that might challenge the higher primates, including humans, if, for example, one wanted to assess a drug's disruptive effects on highly difficult oddity problems.

2.3. Levels 7 and 8: Relational Concepts

Assessing relational concepts at levels 7 and 8 requires that at least one class concept be used, either in a conjunctive, disjunctive, or conditional relationship (level 7) or a biconditional relationship (level 8), with another class concept or with an individual discriminandum. The task requirements must embody the truth-functional equivalents that define the relationship as conjunctive, disjunctive, conditional, or biconditional. The emphasis in discussion here is on level 7, because, apparently, no one has ever attempted to investigate biconditional reasoning by a nonhuman animal.

2.4. Level 7: Conditional and Conjunctive Reasoning

There is a large body of animal learning literature that is addressed under the heading of 'conditional discrimination,' and many of the investigators have explicitly suggested that their animals' performances embodied 'if-then' conditional reasoning. An example of if-then conditional reasoning might be: if the forecast is for rain, then I will take my umbrella. However, most studies are disqualified from having shown evidence for conditional reasoning, because rote associations among the discriminanda and reinforcers might have been learned (see Burdyn and Thomas [2]). The remaining studies purporting to show conditional reasoning are disqualified because the procedures used do not enable one to differentiate between conjunctive and conditional reasoning; i.e. the experimental designs in the investigations have confounded the conjunctive and conditional reasoning solutions to determine the correct choices. Nevertheless, some studies that have confounded the conjunctive and conditional reasoning solutions do provide convincing evidence that either conjunctive or conditional reasoning had occurred, and both are at level 7. Thus, it is suggested that at least some animals have been shown to be capable of level 7 cognitive processing.

A consideration of a study done in my laboratory will show (a) how one can study level 7 concepts using animals and (b) why conjunctive and conditional reasoning has been confounded in animal research. Using stepwise training, Burdyn and Thomas [2] trained squirrel monkeys to use 'sameness,' 'difference,' 'triangularity,' and 'heptagonality' concepts in a paradigm where presentation of a triangle (selected randomly on each trial from a pool of 120 discriminable triangles) was the cue to choose the pair of objects that manifested sameness and presentation of a heptagon (comparable selection and comparable pool of 120 heptagons) was the cue to choose the pair of objects that manifested difference. The order of presentation of a triangle or a heptagon was random, and new pairs of objects manifesting sameness and difference were used on each trial.

Initially, Burdyn and Thomas' [2] conception of the task just described was that it embodied conditional reasoning as reflected in the use of rules that might be expressed as '*if* a triangle is presented, *then* choosing the pair of stimuli that manifested 'sameness' would be correct, but '*if* a heptagon is presented, *then* choosing the pair of stimuli that manifested 'difference' would be correct. However, we eventually realized that the task might also be described as one that embodied conjunctive reasoning and the use of rules that might be expressed as 'a triangle *and* a sameness-pair go together; therefore, choose the sameness-pair when you see a triangle' and 'a heptagon *and* a difference-pair go together; therefore, choose the difference-pair when you see a heptagon.'

In this case, either the conditional-reasoning solution or the conjunctive-reasoning solution would enable an animal to make a correct choice on every trial. Upon further examination of our task and procedural conditions, we realized that the experimental design incorporated the truth-functional conditions for conjunctive reasoning, but the design was incomplete in terms of incorporating the truth-functional conditions for conditional reasoning. Therefore, although our subjects might have reasoned conditionally, we could not say unequivocally that they had. What we could say was that they were either reasoning conditionally or conjunctively. Whether an experimental task that incorporates all the truth-functional equivalents for conditional reasoning can be constructed and administered feasibly and successfully to an animal remains to be determined.

Bourne [1] has used non-verbal tasks with humans that elicit non-verbal evidence for conditional reasoning, and such tasks might conceivably be used with animals (although the use of these tasks successfully with animals does not seem likely). However, to confirm that a subject had performed the task by using conditional reasoning, Bourne [1] relied on the subject's relatively sophisticated verbal explanation, a form of confirming evidence not likely to be provided by even the most linguistically sophisticated chimpanzees. The question of distinguishing between conjunctive and conditional reasoning in animals is much more complicated than can be discussed here without adding several pages to the article, but suffice it to say that there are both methodological and theoretical issues to be resolved.

2.4.1. *Learning set formation*

As mentioned earlier, learning set formation is being addressed separately because it has an extensive history in animal learning as a procedure alleged to involve higher-order processes. Exactly where it fits the 8-level hierarchy depicted in Fig. 1 here is somewhat unclear. On the one hand, learning set appears to involve a kind of reasoning process that might best fit level 7, however, without clearly employing class concepts deemed to be a prerequisite for level 7. On the other hand, the possibility of concurrently rote-learned and applied processes at level 5 as an explanation for learning set formation cannot be eliminated.

Recall in the earlier discussion of olfactory oddity training in rats that Thomas and Noble's rats [18] performed better than chance on trial 2. Such performances have been cited as evidence for what has been called learning set formation or learning to learn [4]. Namely, over the course of training on the olfactory oddity problems, the rats learned to use the information from trial 1, whether it had chosen correctly or not on trial 1, and to apply that information appropriately on trial 2. Such learning has been described as requiring the use of a 'winstay' and 'lose-shift' hypothesis. According to this interpretation, the subject learns that if it wins (gains food) on trial 1 by choosing the object associated with the reinforcer, stay with that object on trial 2 and the remaining trials. Concurrently, the subject learns over the course of several problems that if it loses (does not get food) on trial 1, it should shift to the other object on trial 2 and the remaining trials. Typically, such object quality learning set training presents a given pair of objects for a total of 6 trials at which time a new pair of objects is introduced. Although 6 trials/problem has been typical, other numbers of trials/problem can be used.

Species appear to differ in terms of the rate and level of achievement in acquiring learning sets, for example, see Fig. 7 in Hodos [5] which shows the performances of several species on a common graph. High correlations have been reported between learning set performances and encephalization indices across species [10]. Species encephalization differences associated with learning set formation suggests that pharmacologically manipulating the rate and level of learning set formation might provide a useful behavioral-cognitive-pharmacological assessment tool. However, a cautionary attitude must be taken based on Thomas and Nobles's [18] learning set results from the olfactory oddity study. We found a significantly better rate and level of achievement for our rats compared to the rats whose performances are depicted in Hodos's graph. The rats in Hodos's graph were trained on visual discrimination problems. Warren [20] has argued that species differences in object quality discrimination learning set formation largely reflect species differences in visual capacity rather than learning or cognitive ability per se, thereby, reminding us of the potential confounding of performance and ability that can result from contextual variables, such as visual vs. olfactory cues.

3. Summary of animal achievements in relation to learning, intelligence, and related-cognitive-abilities hierarchy

This section summarizes some general animal achievements mentioned earlier as the details of the hierarchy were being presented in preceding sections. Since some species of all vertebrate classes tested had some degree of success at level 5, this overview will begin at level 5. It is assumed that an animal that can perform successfully at level 5 can perform successfully at levels 1–4.

3.1. Level 5: Concurrent Discrimination Learning

Rensch [9] has shown that fish, reptiles, birds, and mammals are capable of at least some degree of concurrent discrimination learning. Amphibians appear not to have been studied. The focus of Rensch's investigations was to compare small-brain vs. large-brain specimens among the vertebrate classes. Among teleost fish, Rensch compared perch (small-brain) and trout (large-brain) which showed the ability to learn 4 and 6 concurrent discrimination problems, respectively. A small-brain lizard learned 2, a large-brain lizard learned 3, and an iguana learned 5 problems. A 'domestic dwarf race' of bird learned 5 problems and a 'domestic giant race' of bird learned 7 problems. The mammals that Rensch studied and the numbers of problems they learned were mice-7, rats-8, zebra-10, donkey-13, horse-20, and elephant-20.

3.2. Level 6: Class Concept Learning

As noted earlier, if an animal can learn class concepts, then the number of concurrent discriminations that it can learn becomes practically unlimited. Among class concepts, there are two fundamental types, absolute class concepts where at least some of the features that define an object's membership in a class are inherent in each stimulus, and relative class concepts where the defining feature are relative attributes, such as oddity. While several species of birds and mammals appear to be capable of learning absolute class concepts, I am unaware of any study involving birds or non-primate mammals that unequivocally shows evidence for learning a relative class concept. Although there are many claims that birds, especially pigeons and parrots, can learn relative class concepts, it my belief that none have met all the essential criteria and conditions discussed earlier in this article. That is not to say, however, that I believe that such capabilities are beyond those of birds and non-primate mammals. I believe that other species are likely to be found to be capable of learning relative class concepts. The criteria and conditions to be met have been stated clearly. It is likely only a matter of time before a successful investigation occurs.

3.3. Levels 7 and 8: Relational Concepts

Relational concepts involve using class concepts in conjunctive, disjunctive, conditional, and biconditional relationships, but the relationships must be defined by experiments that meet the truth-functional criteria in formal logic that define them. Despite numerous claims that birds, rats, and primates have shown evidence of conditional reasoning, no study has used an experimental design that incorporates the truth-functional criteria for conditional reasoning. Clearly, however, some designs have confounded the possibility of conjunctive and conditional reasoning, and it seems clear that squirrel monkeys, rhesus monkeys, and chimpanzees have accomplished either conjunctive or conditional reasoning. No experiment has been attempted that embodies the truth-functional criteria for biconditional reasoning which is the fundamental type of relational concept learning at level 8.

Table 1
How some paradigms used commonly in behavioral pharmacology likely fit the learning, intelligence, and related-cognitive abilities hierarchy depicted in Fig. 1; See text for further discussion

Paradigm	Relation to Learning, Intelligence and Related-Cognitive-Abilities Hierarchy
Avoidance learning	
Active	Combines levels 2 and 3
Passive	Combines levels 2 and 3
Discrimination	
Concurrent	Level 5
Simultaneous	Level 3
Successive	Level 3
List learning	Level 4
Maze tasks (see Note)	Level 4
Navigation (see Note)	Level 4
Set shifting	See Learning Set Formation in text.
Spatial alternation	Level 4

Note: Whether working memory or recognition memory are of interest with respect to maze learning or whether cue navigation or place navigation are of interest is not relevant to the question of the underlying level of learning ability required. This does not diminish their importance in the context of other cognitive abilities.

4. Behavioral pharmacology and the learning, intelligence, and related-cognitive-abilities hierarchy

Table 1 summarizes relationships of some commonly used behavioral paradigms in pharmacology to levels in the hierarchy. Some general points regarding this table need to be made.

First, it is assumed that none of the discriminanda associated with any of the tasks are exemplars of class concepts, and this seems to be the typical case in behavioral pharmacology. Of course, exemplars of class concepts could be used with any of the listed paradigms, in which case, the task automatically becomes one at level 6 or possibly higher.

Second, Table 1 only addresses the fundamental learning ability that is required to perform each of the tasks listed. The table does not assess the role of special types of memory, attention, perception, or other cognitive abilities that might be useful, if not essential, to successful performance of a given task. There is also no attempt to address possible differences that might result from, for example, a task that requires the inhibition of skeletal muscle responding (e.g. passive avoidance learning) compared to a task that requires the activation of skeletal muscle responding (active avoidance). Such differences may affect the manifestation of learning, but they do not necessarily require different fundamental learning processes.

Further, the table does not take into account differential evolutionary advantages that species might have, for example, for spatial learning, utilization of visual vs. olfactory cues, etc. In terms of comparing species or, for example, generalizing the effects of pharmacological manipulations of cognitive abilities related to learning ability and intelligence, a goal should be to reduce the role of such contextual variables as sensory, motor, and motivational preferences or evolutionary advantages by providing optimal conditions for each species.

Finally, there are many variations possible for all the tasks listed in the table, and the table assumes the simplest variation. For example, as noted above, the use of exemplars of class concepts as discriminanda may automatically elevate any task to level 6 or higher. For a different example, active avoidance training in a shuttle-box can be done in one direction only (one-way active avoidance); i.e. the animal is always required to go from, say, the left compartment to the right compartment; such learning includes Pavlovian conditioning (level 2) and S-R learning (level 3). Alternatively, two-way avoidance training might be done, in which case the animal is required to go one direction on 1 trial and the opposite direction on the next trial, etc.; in this case, Chaining (level 4) is added to the level-2 and level-3 requirements.

4.1. Interactive models of cognitive abilities in monkeys and humans

As discussed earlier, one can construct hierarchies of oddity problems. We have done studies using such hierarchies of oddity problems with squirrel monkeys and with humans [8,11,16]. We have also studied numerousness judgments by both squirrel monkeys and humans using similar tasks [12,15]. The tasks required the subjects to discriminate between two arrays of items when the numbers or numerousness of items in the arrays provided the only reliable cues. Our monkeys accurately discriminated as many as 7 vs. 8 items, and we hypothesized that they did so using a process that did not involve counting. Thomas et al. [19] used humans to test whether such judgments could be done without counting by using testing conditions which we believe prevented counting and our evidence showed that they could. To prevent counting we used 200-ms stimulus presentation times and a poststimulus masking stimulus to prevent counting based on afterimages.

Such studies show the feasibility of having cognitive models and procedures that can be used meaningfully with both animals and humans. The value of such procedures to neuroscientists should be considerable.

4.2. Concluding remarks

It is likely that species representative of all vertebrate classes are capable of at least some degree of success at level 5 of the learning/intellectual/cognitive abilities hierarchy shown here in Fig. 1. Several species of birds and mammals are capable of learning and using absolute class concepts (level 6), and it is likely that many more species yet to be tested will prove to have such capability also. Presently, the definitively conclusive reports of non-human animals using relative class concepts (also level 6) appears to be limited to primates, human and non-human, but it is reasonable to believe that some species of non-primate animals will be successful as well. The best evidence to date for the use of class concepts in conjunctive, disjunctive, or conditional relationships (level 7) appears to be limited to primates and to the use of procedures that favor interpretations of conjunctive reasoning. It is reasonable to think that some non-primate species may succeed at level 7, too.

There are many proven procedures readily available to the behavioral pharmacologist and other behavioral neuroscientists that address higher-order cognitive processes in definitive and practical ways, and there are suitable cognitive models and methods that can be used meaningfully with human and non-human animals. Until behavioral neuroscientists begin to use tasks that demand that animals use higher-order cognitive abilities, the vast potential for research that might be done will remain unfulfilled and the applicability of animal models to humans will remain too limited.

References

[1] Bourne, L.E., Jr., Knowing and using concepts, *Psychol. Rev.*, 77 (1970) 546–556.

[2] Burdyn, L.E., Jr. and Thomas, R.K., Conditional discrimination with conceptual simultaneous and successive cues in the squirrel monkey (*Saimiri sciureus*), *J. Comp. Psychol.*, 98 (1984) 405–413.

[3] Gagne, R.M., *The Conditions of Learning*, Holt, Rinehart and Winston, New York, NY, 1970, 407 pp.

[4] Harlow, H.F., The formation of learning sets, *Psychol. Rev.*, 56 (1949) 51–65.

[5] Hodos, W., Evolutionary interpretation of neural and behavioral studies of living vertebrates. In F.O. Schmidt (Ed.), *The Neurosciences: Second Study Program*, Rockefeller University Press, New York, NY, 1970, pp. 26–39.

[6] Langworthy, R.A. and Jennings, J.W., Odd ball, abstract, olfactory learning in laboratory rats, *Psychol. Rec.*, 22 (1972) 487–490.

[7] Lu, X.-C.M., Slotnick, B.M. and Silberberg, A.M., Odor matching and odor memory in the rat, *Physiol. Behav.*, 53 (1993) 795–804.

[8] Noble, L.M. and Thomas, R.K., Oddity and dimension-abstracted oddity in humans, *Am. J. Psychol.*, 98 (1985) 549–557.

[9] Rensch, B., The evolution of brain achievements, *Evol. Biol.*, 1 (1967) 26–68.

[10] Riddell, W.I. and Corl, K.G., Comparative investigation of the relationship between cerebral indices and learning abilities, *Brain Beh. Evol.*, 14 (1977) 385–398.

[11] Steirn, J.N. and Thomas, R.K., Comparative assessments of intelligence: performances of *Homo sapiens sapiens* on hierarchies of oddity and sameness-difference tasks, *J. Comp. Psychol.*, 104 (1990) 326–333.

[12] Terrell, D.F. and Thomas, R.K., Number-related discrimination and summation by squirrel monkeys (*Saimiri sciureus sciureus* and *S. boliviensus boliviensus*) on the basis of the number of sides of polygons, *J. Comp. Psychol.*, 104 (1990) 238–247.

[13] Thomas, R.K., The evolution of intelligence: an approach to its assessment, *Brain Behav. Evol.*, 17 (1980) 454–472.

[14] Thomas, R.K., A critique of 'Relational Rule Learning in the Rat', *Psychobiology*, 22 (1994) 347–348.

[15] Thomas, R.K., Fowlkes, D. and Vickery, J.D., Conceptual numerousness judgments by squirrel monkeys, *Am. J. Psychol.*, 93 (1980) 247–257.

[16] Thomas, R.K. and Frost, G.T., Oddity and dimension-abstracted oddity (DAO) in squirrel monkeys, *Am. J. Psychol.*, 96 (1983) 51–64.

[17] Thomas, R.K. and Lorden, R.B., Numerical competence in animals: a conservative view. In S.T. Boysen and E.J. Capaldi (Eds.), *The Development of Numerical Competence: Animal and Human Models*, Lawrence Erlbaum, Hillsdale, NJ, 1993, pp. 127–147.

[18] Thomas, R.K. and Noble, L.M., Visual and olfactory oddity learning in rats: what evidence is necessary to show conceptual behavior? *Anim. Learn. Behav.*, 16 (1988) 157–163.

[19] Thomas, R.K., Phillips, J.A. and Young, C.D., Numerous judgments by *Homo sapiens* in a species-comparative context. Presented at the Meeting of the Psychonomic Society in New Orleans, LA, 1990.

[20] Warren, J.M., Possibly unique characteristics of learning by primates, *J. Hum. Evol.*, 3 (1974) 445–454.