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Author: Markham, Kimberly M.; Mintzes, Joel J. & Jones, M. Gail

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The Structure and Use of Biological Knowledge about Mammals in Novice and Experienced Students

Kimberly M. Markham
Joel J. Mintzes
Department of Biological Sciences
University of North Carolina at Wilmington
M. Gail Jones
School of Education
University of North Carolina at Chapel Hill
USA

ABSTRACT

This study explored differences in the way novice and experienced students organize and use biological knowledge within the domain of mammals. Subjects were enrolled in a college-level, introductory biology course for nonscience majors (n=25) and an advanced course in mammalogy intended for upper-division and graduate-level students (n=25). Each subject constructed a concept map and then participated in a clinical interview, during which an exhaustive set of descriptive propositions about 20 mammals depicted in line drawings was generated. Subjects subsequently sorted the mammals into homogeneous groups. Results of concept mapping reveal that experienced students possess a substantially more extensive, complex, and integrated knowledge base characterized by significantly greater numbers of concepts, relationships, levels of hierarchy, branchings, and crosslinks. Results of clinical interviews and sorting task demonstrate that these differences are linked to the emergence of a new repertoire of implicit, superordinate concepts which orders students' understandings, the enhanced use of inferential reasoning strategies, and the development of a scientifically acceptable system of assigning class membership.

INTRODUCTION

Recent research in biological education has focused on two significant areas: students' alternative conceptions of natural phenomena (Arnaudin and Mintzes, 1985; Mintzes and Arnaudin, 1984; Trowbridge and Mintzes, 1985, 1988; Wandersee, Mintzes, and Arnaudin, 1987, 1989; Wandersee, Mintzes, and Novak, in press) and the nature of the novice-expert shift (Smith, 1988, 1990, 1992). Studies of alternative conceptions have demonstrated that students subscribe to a wide variety of viewpoints within the domain of biology. For example, it has been demonstrated (Trowbridge and Mintzes, 1985) that students of all ages subscribe to a highly restricted understanding of the concept animal, often using it interchangeably with mammal. For these students an animal is a four-legged, furry creature found in the home, on farms, or in a zoo. Insights into "naive" students' views provide a starting point for studies of the novice-expert shift.

Current knowledge on the nature of expertise in biology is derived largely from research efforts of cognitive psychologists, who have contributed substantially to our understanding of knowledge structures, memory development, and semantic processing (Chi, 1978, 1985; Chi and Koeske, 1983; Collins and Loftus, 1975). In attempting to understand these elements cognitive psychologists have focused on expertise in a wide range of knowledge areas, including chess playing (DeGroot, 1965; Chase and Simon, 1973; Simon and Chase, 1973), physics problem-solving (Larkin et al., 1980), medical diagnosis (Groen and Patel, 1988), computer programming (Soloway et al., 1988), restaurant order-taking (Ericsson and Polson, 1988), and typewriting (Gentner, 1988), to name a few.

There are several important findings from the research on novice and expert performances which lie within the boundaries of this study (Chi, Glaser, and Farr, 1988). For example, experts have a great amount of domain-specific knowledge. Inventories of cognitive structure reveal a well-differentiated, highly integrated knowledge base within the domain of expertise. Experts also perceive large, meaningful patterns in their domain; their perceptual superiority is a reflection of the knowledge base organization. Additionally, experts perceive and represent knowledge in their domain at a deeper, more principled, level than novices. In other words, experts are more implicit whereas novices are more explicit, or surface-feature oriented. Experts' knowledge is tightly organized around a set of abstract concepts which orders their understandings and enables them to infer information that is not readily observable.

The term expert is relative. For example, in Gobbo and Chi's (1986) study of how knowledge of dinosaurs is structured and used by expert and novice children, the experts were 7-year-old children who had scored highest on a locally constructed pretest. Gobbo and Chi examined how expert children make more efficient use of their knowledge because of its more cohesive and integrated structure. Gobbo and Chi's exploratory study was used as a model for the present research. The procedure and several measures for assessing differences in knowledge structures and uses were closely followed. Concept mapping offered an additional technique for assessing cognitive structure. Gobbo and Chi offered three major conclusions: novice children focus on the explicit features of concepts, while expert children focus on more implicit concepts; expert children's knowledge is more structured, more cohesive and integrated; and expert children use their knowledge more efficiently by drawing inferences, reasoning analogically, and contrasting class membership.

Few studies on the nature of expertise have focused on the biological sciences. The present research investigates the nature of expertise in the domain of mammals. The domain of mammals was chosen for two reasons. First, in previous work it has been shown that novices have a "highly restricted" view of animals, often applying the label animal exclusively to mammals (Trowbridge and Mintzes, 1988). Findings suggest that for novices of virtually all ages the concept animal has a much narrower meaning than that assigned to it by biologists. Accordingly, it is reasonable to pursue this issue further by studying how novice and experienced students differ in the content of their knowledge base and in the ways they structure and use their knowledge about mammals. The second reason for choosing the concept mammals is methodological. The selected domain of biological knowledge had to be somewhat familiar, even to those with no formal training in biology, in order to contrast the knowledge structures of novice and experienced students. Based on our earlier study, the concept mammals appears to fit that requirement reasonably well.

The purpose of this research, therefore, was to compare and contrast the structure and use of biological knowledge about mammals in novice and experienced students through concept mapping, clinical interviews, and sorting tasks in order to test the following hypotheses:

1. Experienced students have a larger, more extensive, and more complex knowledge base than novices. This is reflected in a greater number of concepts, valid relationships, branchings, and levels of hierarchy in the concept maps, and a greater number of scientifically acceptable propositions about mammals in interview transcripts.

2. Experienced students demonstrate a more cohesive and integrated knowledge base. Their concept maps display more crosslinks between concepts, and interview transcripts reveal a greater number of syntactic connections between related propositions.

3. Experienced students are able to use their knowledge more efficiently, displaying a greater ability to reason inferentially and analogically. This ability is reflected in the use of implicit, superordinate concepts and semantic comparisons in the interview transcripts.

4. Experienced students perceive large, meaningful patterns in their domain of expertise which differ qualitatively from those perceived by novices. These differences are reflected in students' sorting behaviors and rationales.

METHOD

Overview

Three techniques were used to explore differences in the way novice and experienced students structure and use their biological knowledge: concept mapping, clinical interviews, and a card sorting task. Initially, subjects were instructed to concept map their knowledge of mammals, following verbal and written instructions on how to construct a concept map. Each subject then participated in a taped interview in which 20 labelled, line drawings of mammals were presented. Subjects responded by describing "everything you know" about each mammal. Finally, subjects sorted the drawings into homogeneous groups. Rationales for the groupings were then elicited.

Subjects

Subjects (n=50) attended a regional campus of a state university in southeast North Carolina. The institution enrolls approximately 8,000 students, of whom more than 90 percent are in-state residents. The mean combined SAT score of incoming freshmen is 925.

Novice. The novices were 25 students who enrolled in a college-level introductory biology course designed for nonscience majors. This course introduces the diversity of life and general principles governing living systems, from molecular biology to ecology. The novice group consisted of 8 males and 17 females, including 15 freshmen, 7 sophomores, and 3 juniors. Students who enroll in the course do so to satisfy a basic studies requirement of one laboratory course in the life sciences. Typically, these students have taken a high school course in biology and are majoring in either business, education, or one of the humanities, fine arts, or social sciences. Prior knowledge of biological concepts is generally minimal.

Experienced. The 25 experienced students were enrolled in an upper-level mammalogy course designed for college juniors, seniors, and graduate students. This course emphasizes the evolution, taxonomic relationships, physiological and structural adaptations, and life histories of mammals. The experienced group consisted of 11 males and 14 females, including 10 juniors, 9 seniors, and 6 graduate students. Students who enroll in the course have selected to major in biology or marine biology and have taken a minimum of three previous courses in the discipline, including a two-semester introductory sequence and a general introduction to animal biology. The majority of students has taken additional coursework in the biological sciences; and some advanced undergraduates and graduate students have specialized interest in vertebrate natural history.

Concept Mapping

Concept mapping was employed to provide a two-dimensional representation of the knowledge structures held by students in the domain of mammals (Markham, Mintzes, and Jones, in press). The techniques employed were those developed at Cornell University (Novak and Gowin, 1984). Each subject was provided several large sheets of paper, a pencil, and concept mapping instructions (Arnaudin, 1985). The instructions directed the subject to begin with the concept mammals and to draw relationship lines to other concepts believed to be related to mammals. Other relationship lines between related concepts were encouraged. It was emphasized that there was no incorrect way to map one's knowledge of mammals as long as two rules were abided: concepts must be minimally worded and all relationship lines must be clearly labelled.

Concept maps were scored using a modified version of Novak and Gowin's scoring method. Points were given for the numbers of concepts, relationships, branchings, hierarchies, crosslinks, and examples represented in each map. The numbers of concepts and relationships are taken as indications of the extent of knowledge in the domain of mammals. One point was assigned to each concept and to each valid relationship. The branchings in a map represent progessive differentiation in the knowledge domain. One point was assigned to the first branching and three points to each successive branching. Hierarchies are a representation of knowledge subsumption. Five points were given for each hierarchy in the map. The presence of crosslinks in a map reflects the extent of knowledge integration. Ten points were assigned to each crosslink. Examples in a concept map represent specificity of knowledge. One point was awarded for each example presented.

Novak and Gowin suggest assigning a cumulative concept mapping score, obtained by summing the weighted partial scores; however, in this study each of the six observed aspects of the concept map was analyzed as a separate entity. A one-way analysis of variance was performed on the concept mapping scores using the NPAR1WAY procedure of the VAX SAS system.

Clinical Interview

Upon completion of the concept mapping task, 20 labelled line drawings of mammals were presented individually to the subject. Of these, ten had been shown to be recognizable to more than half of a comparable group of novice biology students (<u>more familiar mammals</u>) and the remaining ten were recognizable to fewer than half (<u>less familiar mammals</u>). Drawings of the more familiar mammals depicted a beaver, chimpanzee, kangaroo, koala, lion, platypus, porcupine, rabbit, raccoon, and zebra. The less familiar mammals included the armadillo, ferret, hedgehog, lemur, manatee, mole, opossum, pika, spiny anteater, and tree shrew. Using a strategy developed by Gobbo and Chi (1986), a line drawing of a more familiar mammal was presented and the subject was addressed as follows:

O.K. __________________ (subject's name), here is a(n) (mammal).

Tell me everything you know about this mammal.

The remaining 19 cards were randomly selected. The subject was given as much time as needed to respond to each stimulus and was instructed to indicate when knowledge of the mammal was exhausted.

The tape-recorded responses were transcribed verbatim and divided into propositional statements about the mammals. The statements were then classified into categorical groups on the basis of structural attributes. The validity of each proposition was ascertained by a professional mammalogist in consultation with two widely used mammalogy textbooks (DeBlase and Martin, 1981; Vaughan, 1986). Differences in the proportions of scientifically acceptable propositions among groups were analyzed using the Kruskal-Wallis test, a nonparametric analogue of analysis of variance employing a chi-square significance approximation.

Sorting Task

Immediately following the interview, the subject was handed all 20 cards and given the following instructions:

I would like you to take these drawings and put all of the mammals that belong
together in the same group. You may make as many groups as you wish.
There may be as few or as many mammals as you wish in each group.

The subject was left alone to sort the cards. Upon completion of the sorting task the subject was addressed as follows:

O.K. ________________ (subject), I see that you have made (number) groups
with the cards. Let's take a look at your first group. I see that it is made up of the
_____________ (mammals). Why did you decide to put these mammals together
in the same group?

This process was continued until the subject had provided a statement of rationale for each group.

The tape-recorded responses of the sorting task were transcribed verbatim and divided into statements of rationale. The sorting rationales were then classified into categorical groups on the basis of structural attributes. A Kruskal-Wallis test was performed on the proportions of scientifically acceptable rationale statements. The mammal sortings were analyzed using a multidimensional scaling procedure (Kruskal and Wish, 1991; Young and Rheingans, 1991). In multidimensional scaling, semantic proximities derived from a sorting task are used to develop two-dimensional configurations that reflect the "hidden or underlying structure" in a knowledge domain. Since the configurations are two-dimensional representations of proximities in multidimensional space, points that appear proximate in the configuration may diverge when viewed in other dimensions.

RESULTS AND DISCUSSION

Concept Mapping

Figures 1 and 2 are examples of concept maps constructed by novice subjects, Kelly and Brian, and figures 3 and 4 represent partial concept maps of experienced subjects, Eileen and Kevin. (The concept maps of the latter group were too extensive for representation in a single figure.) These examples of concept maps are presented for the purpose of demonstrating and comparing domain-specific knowledge structures. The representations are not meant to portray a "typical" novice or experienced subject.

Overall, novices' concept maps are less extensive and complex than those of experienced subjects. Kelly and Brian produced fewer numbers of concepts and relationships related to the knowledge domain of mammals. The numbers of concepts depicted in their maps are 13 and 18, respectively, and the numbers of valid relationships are 12 and 17. On the other hand, the numbers of concepts for Eileen's and Kevin's entire maps are 49 and 339, respectively, and the numbers of valid relationships are 64 and 453.

The majority of the propositions employed by both exemplary groups is valid. However, experienced subjects displayed an array of domain-specific, superordinate concepts that organized much of their knowledge structure. These concepts are generally not present in novices' concept maps. For example, Kelly suggested that some mammals "can live in water," "...on land," and "...in the air," whereas Eileen provided the superordinate concepts "fossorial," "scansorial," and "arboreal." Brian used the term "live birth," but Kevin indicated that mammals may be "viviparous." Brian incorporated the term "pouch," whereas Eileen and Kevin employed the concept "marsupium."

Additionally, differences in complexity can be seen in the numbers of branchings and hierarchies. Experienced subjects tended to branch from concepts more frequently and create more hierarchies than did novice subjects, whose concept connections are more linear. Eileen's and Kevin's branching scores are 40 and 410, respectively, and their hierarchy scores are 30 and 50. However, Kelly and Brian have branching scores of 4 and 16, respectively, and their hierarchy scores are 15 and 15.

Experienced subjects' concept maps are also more integrated, as revealed in greater numbers of crosslinks between concepts. Eileen's partial concept map displays a crosslink between the concepts "underdeveloped young" and "live young," and another between "live young" and "out of pouch." Kevin's partial concept map displays crosslinks between the concepts "echidna" and "Australian," "North America" and "opossums," and "viviparous" and "reproductive strategy." The crosslink scores for Eileen's and Kevin's entire concept maps are 40 and 430, respectively. The only crosslink in Brian's map is the connection between the concepts "carnivores" and "hair." Kelly's map shows no crosslinks, a characteristic of many novices.

Experienced subjects generally produced more specific examples of mammals in their concept maps. The specific examples of mammals are often terminal in a line of concepts because concept maps tend to flow from general concepts (mammals) to more specific concepts. Kevin's partial map displays the examples "platypus," "echidna" (which are crosslinked to the concept "Australian"), and "opossums." The numbers of examples provided in Eileen's and Kevin's entire concept maps are 31 and 103, respectively. The novices provided fewer examples of mammals. Kelly incorporated the examples "bats," "whales," and "people." Brian's map displays the examples "deer," "rabbit," "wolves," "lion," "kangaroo," and "opossum." The numbers of examples provided by Kelly and Brian are 3 and 6, respectively.

The preceding descriptions represent distinguishing differences in the structural complexity of novice and experienced subjects' concept maps. Additionally, there are unique features seen in the organizational patterns of maps within the novice and experienced groups. For example, Kelly based her structure primarily on where mammals "can live," such as in "air," "water," or on "land" and on body characteristics. On the other hand, Brian structured his concept map around mammalian diet and reproduction. Similar differences in organizational patterns can be observed in the experienced subjects' concept maps. Eileen structured her map on the basis of mammalian habitat, reproductive strategies, and dietary patterns. However, Kevin's map is overwhelmingly taxonomic, with a second emphasis on mammalian characteristics.

Figure 5 displays the mean concept mapping scores for the entire novice and experienced groups. Experienced subjects scored significantly higher in all six categories: concepts, relationships, branchings, hierarchies, crosslinks, and examples. The mean numbers of concepts produced by novice and experienced subjects were approximately 25 and 85, respectively. Novices displayed a mean number of approximately 27 relationships in their concept maps, whereas experienced subjects averaged over 99. In the branching category novices scored a mean of approximately 15, and experienced subjects averaged almost 60. Novices' and experienced subjects' mean scores for hierarchies were approximately 19 and 31, respectively, and for crosslinks were 22 and 64. Finally, novices provided a mean number of 4 examples in their concept maps, whereas experienced subjects produced an average of approximately 17.

Clinical Interviews

When subjects were asked to "tell me everything you know" about twenty mammals depicted in the line drawings, substantial differences were revealed in the structure and use of knowledge by novice and experienced students (Figures 6-9). In terms of sheer quantity and scientific acceptability of the responses, the novices generated an average of approximately 120 propositions compared to about 180 among the advanced students. Of this number, approximately 65% of the former and 80% of the latter were judged to be scientifically acceptable (Figure 6). Only a small proportion of each (6-10%) might be labelled alternative, or scientifically unacceptable, propositions. Interestingly, about one fourth of all the novice propositions were found to be too subjective to evaluate for scientific acceptability (e.g., "Kangaroos can hop really high."). A small proportion of propositions in both groups (2-3%) was anthropomorphic in character (e.g., "Lions are lazy.").

Figures 7 and 8 summarize the types and proportions of major organizing concepts (organizational patterns) revealed in the interview transcripts. Of the twenty-four conceptual categories identified (1-24), differences among subject groups were found in seventeen. The most striking feature is the emergence of a vast new repertoire of implicit, superordinate concepts which orders the knowledge base of the experienced students. These superordinate concepts provide a parsimonious, yet very powerful, mechanism for conveying significant biological adaptations which are key to an understanding of phylogenetic relationships among mammalian species. Among the most important of these are concepts that order knowledge on the basis of taxonomic classification (1), biogeographical realm of distribution (5), habitat (7), dietary pattern (10), locomotion (12), behavior (19), reproductive strategy (21) and newborn maturity (24).

The emergence of a taxonomic classification system is striking. Almost 20% of the propositions generated by the advanced students were taxonomic in character. The most common of these identified the order or family to which the animal belongs (e.g., "Zebra is a perissodactyl in the family Equidae."). This is important because the accepted system of classification assigns great significance to the biological adaptations associated with family membership.

Another significant trend is the consistent shift from the use of simple, descriptive propositions among the novices to superordinate concepts which subsume them. This trend is seen in all of the conceptual categories identified above. For example, in categories 6 and 7 many of the novices suggested that "lemurs live in trees" while the advanced students were more likely to indicate that "lemurs are arboreal." It is important to note that "living in trees" and "arboreal" are not synonymous; the latter conveys a significant adaptation that the lemur shares with a large number of related animals. Hence this shift may be viewed as a strong indication of greater cohesion in the knowledge base of the experienced students.

Similarly in categories 9 and 10, the novices were more likely to suggest that "lions eat meat" whereas the experienced students often indicated that "lions are carnivores." In categories 11 and 12, we see a shift from statements like "kangaroos hop" to "kangaroos are saltatorial." In the area of behavioral characteristics (18 and 19), the novices commented that certain mammals "live in groups" or "come out at night;" phrases which become "gregarious" and "nocturnal" in advanced students. This trend is also found in the areas of reproductive strategy (from "lays eggs" to "monotreme") and newborn maturity (from "helpless" to "altricial"). One other finding that merits emphasis is the shift away from propositions describing explicit body features, especially common body coverings such as hair, fur, and skin. This single category accounted for some 18% of the novice propositions, dropping to 5-6% in the experienced group.

Figure 9 summarizes what was learned from the clinical interviews about the structural complexity and applications of the knowledge base. Structurally, the number of syntactic connectives used by the experienced students was almost double that of the novices. This is taken as an indication of greater cohesion. More than a quarter of the propositions generated by the former group were syntactically linked to adjacent propositions in the interview transcripts. This finding is consistent with differences in the number of crosslinks found in the subjects' concept maps, which also greatly favored the experienced students.

In the area of knowledge application, the number of semantic comparisons offers an indication of analogical reasoning. Examples of this are the propositions, "The zebra looks like a horse" (a direct mammal-mammal comparison); "The spiny anteater has spines like a porcupine" (a mammal-attribute-mammal comparison), and "The kangaroo is the largest marsupial in Australia" (an absolute comparison). The transcripts revealed few such propositions, however the proportions favored the novices. This is an unexpected finding and is inconsistent with that of Gobbo and Chi (1986).

Finally, the results summarized in categories 27-30 give some indication of enhanced use of inferential reasoning strategies among the experienced students. Specifically, it appears that the transition from novice to experienced student is characterized by a decline in the proportion of explicit propositions (i.e., those that can be made on the basis of direct observation) and a concurrent rise in the proportion of implicit propositions (i.e., those that cannot be made on the basis of direct observation). Furthermore, this trend is found among both the "less familiar" mammals as well as the "more familiar" ones. This suggests that experienced students are capable of using their knowledge base to infer new information about mammals, even about those with which they are relatively unfamiliar. Presumably, this ability derives from the structurally more complex knowledge base possessing significant numbers of superordinate, implicit concepts and the strong hierarchical organization, and tight knit crosslinks which permit learners to draw inferences and make deductions more readily.

Sorting Tasks

The configurations resulting from the multidimensional scaling procedure (Figures 10 and 11) provide strong evidence that novice and experienced students differ substantially in the underlying dimensions they use to assign class membership. It appears that the novices rely heavily on explicit morphological features and habitat for this purpose, whereas the experienced students depend on the taxonomically accepted dimensions of reproductive strategy and dietary pattern.

In the novice configuration (Figure 10), the porcupine, hedgehog and spiny anteater (representing three quite divergent taxonomic orders) were frequently grouped together, presumably because of the presence of distinct "spines." The rabbit and kangaroo "hop" and "have long ears;" the zebra and lion are both found in Africa; the pika and mole are "small, and rodent-like." Mammals depicted on a tree branch, including the koala, lemur, raccoon and tree shrew were typically grouped together as were the "water-dwellers" (i.e., beaver, manatee and platypus), each depicted with its characteristic swimming adaptations--flattened tail, flippers, and webbed feet.

In marked contrast, the experienced students' configuration (Figure 11) is clearly a reflection of taxonomic dimensions, presumably with their phylogenetic meanings intact (although the latter is open to question). It appears that the experienced students ordered the mammals into recognizable taxonomic groupings; the hedgehog and mole in Order Insectivora, the pika and rabbit in Order Lagomorpha and so forth. Such a grouping implies that students understand the underlying dimensions that form the basis of the accepted taxonomic system, namely reproductive strategy and dietary pattern.

As a further check on the underlying dimensions the students used in assigning class membership we asked them, after completing the sorting task, to tell us "why you decided to put these mammals together in the same group." The rationale given by the students tended to support our interpretations (Figure 12). Virtually all of these statements given by the experienced students were implicit in character, compared to approximately 50% among the novices. Furthermore nearly two-thirds of the former were taxonomic (e.g., "They are all Marsupials;" "They are all Insectivores"). On the other hand, the novices indicated that they relied primarily on explicit, anatomical features and habitat in their decisions.

CONCLUSIONS

The results of this study suggest that novice and experienced students differ substantially in the structural complexity and organizational pattern of their knowledge bases within the domain of mammals. Concept mapping demonstrates that the knowledge base of experienced students is more extensive, possessing greater numbers of concepts and scientifically acceptable propositions. This knowledge is also substantially more complex as revealed in the extent of concept differentiation, subsumption, and integration within the maps. Results from the clinical interviews and sorting tasks offer additional evidence of differences in structural complexity and show that the structurally more complex knowledge base of experienced students is linked to an organizational pattern ordered around a vast network of implicit, superordinate concepts which orders their knowledge. This network results in qualitative superiority in the use of inferential reasoning strategies within the domain and the ability to assign class membership, or phylogenetic affinities, on the basis of meaningful, underlying dimensions.

IMPLICATIONS

Findings of this study suggest that novices and experienced students differ substantially in the way they organize their knowledge in a biological domain that is frequently included in courses at the secondary school and college levels. Furthermore, it appears that the knowledge structures that advanced students possess strongly mirror those presented in formal course documents such as textbooks, curriculum guides, and a variety of other instructional materials. These findings are not particularly surprising, after all, for many instructors the primary goal of science teaching is conceptual change and those students whose terminal knowledge structures approximate the "scientifically acceptable" ones are rewarded. What is of greater significance is the intimate link that appears to exist between the way students organize their knowledge and their ability to use that knowledge in novel situations. Not all knowledge structures are of equal worth. As Smith (1992) has shown, even experts within a discipline differ substantially in the way they organize their knowledge and the organization is strongly related to how the knowledge is used. In our judgment this is the most important implication of this study, especially in an age when curriculum designers are proposing "radical" changes in the content of secondary school science programs (Bybee, 1985; National Science Teachers Association, 1992). The way we design our curricula certainly makes a difference. We suggest that the time has come to begin viewing curricular issues through a cognitive perspective, recognizing that the way we organize knowledge has a profound impact on how learners think.

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FIGURE CAPTIONS

Fig.1. Kelly's concept map: An example from the novice group.

Fig.2. Brian's concept map: An example from the novice group.

Fig.3. Portion of Eileen's concept map: An example from the experienced group.

Fig.4. Portion of Kevin's concept map: An example from the experienced group.

Fig.5. A comparison of concept mapping scores of novice and experienced students.
[$F(1,48)$ = 15.3** (concepts); 14.3** (relationships); 7.6** (branchings);
23.1** (hierarchies); 4.3** (crosslinks); 8.3** (examples)]

Fig.6. Proportions of propositions about mammals given by novice and experienced
students. [$X^2(1, N=50)$= 22.9** (scientific); 14.8** (alternative);
18.5** (subjective); 6.6* (anthropomorphic)]

Fig.7. Proportions of scientifically acceptable propositions about mammals revealing
organizational pattern of the knowledge base (categories 1-12).
[$X^2(1, N=50)$= 34.5** (1); 20.1** (2); 8.2** (3); 6.2* (4); 21.1** (5); 19.0** (6);
41.3** (7); 12.1** (8); 15.0** (9); 22.9** (10); 20.4** (11); 42.0** (12)]

Fig.8. Proportions of scientifically acceptable propositions about mammals revealing
organizational pattern of the knowledge base (categories 13-24).
[$X^2(1, N=50)$= 0.7 (13); 25.5** (14); 0.2 (15); 0.02 (16); 0.1 (17); 7.2** (18);
19.1** (19); 1.7 (20); 28.3** (21); 3.2 (22); 3.1 (23); 10.6** (24)]

Fig.9. Proportions of propositions revealing structural complexity and applications of
the knowledge base (categories 25-30). [X^2(1, N=50)= 15.6** (25); 10.8** (26);
25.2** (27); 30.9** (28); 19.7** (29); 25.2** (30)]

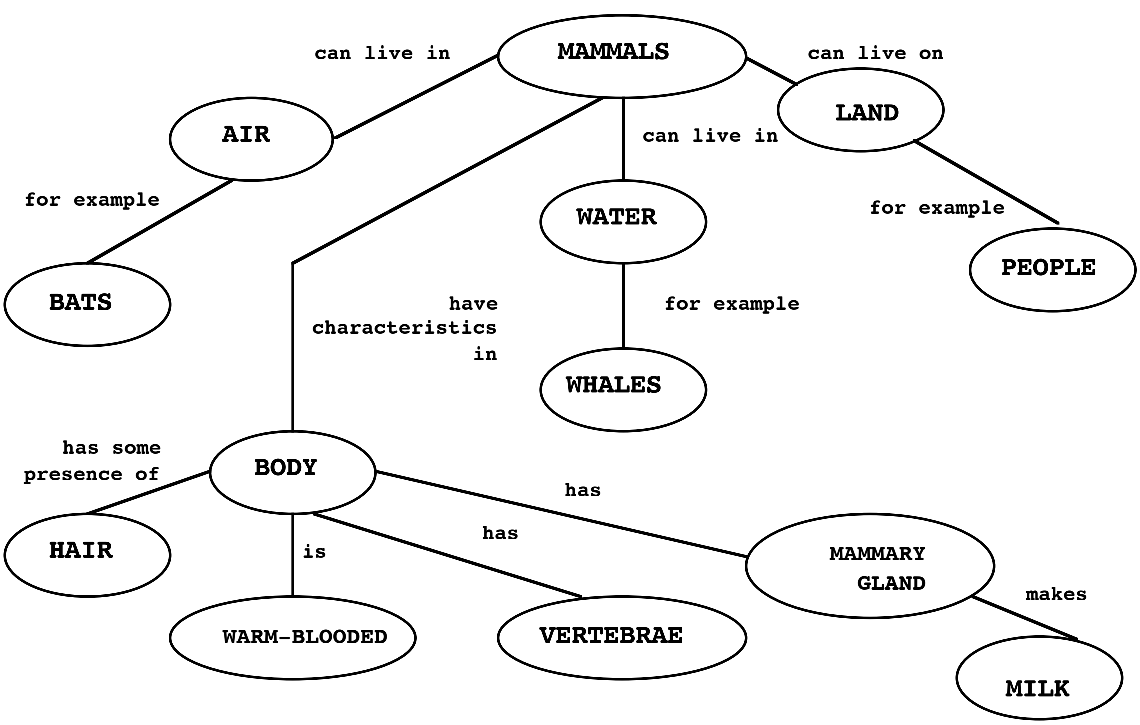
Fig.10. Two-dimensional configuration from multidimensional scaling procedure on
novice students' mammal sortings.

Fig.11. Two-dimensional configuration from multidimensional scaling procedure on
experienced students' mammal sortings.

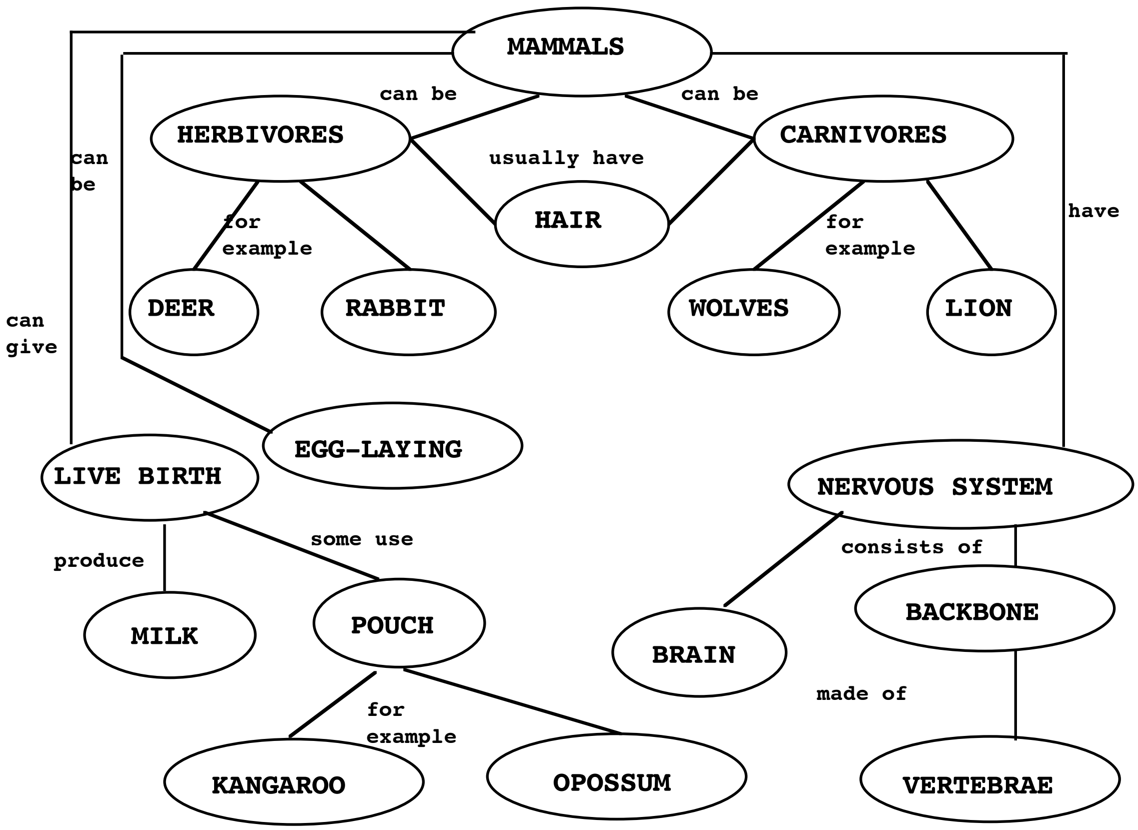
Fig.12.
Proportions of sorting rationales given by novice and experienced students
(categories 1-5). [X^2(1, N=50)= 25.1** (1); 30.8** (2); 5.7* (3);
0.2 (4); 25.1** (5)]

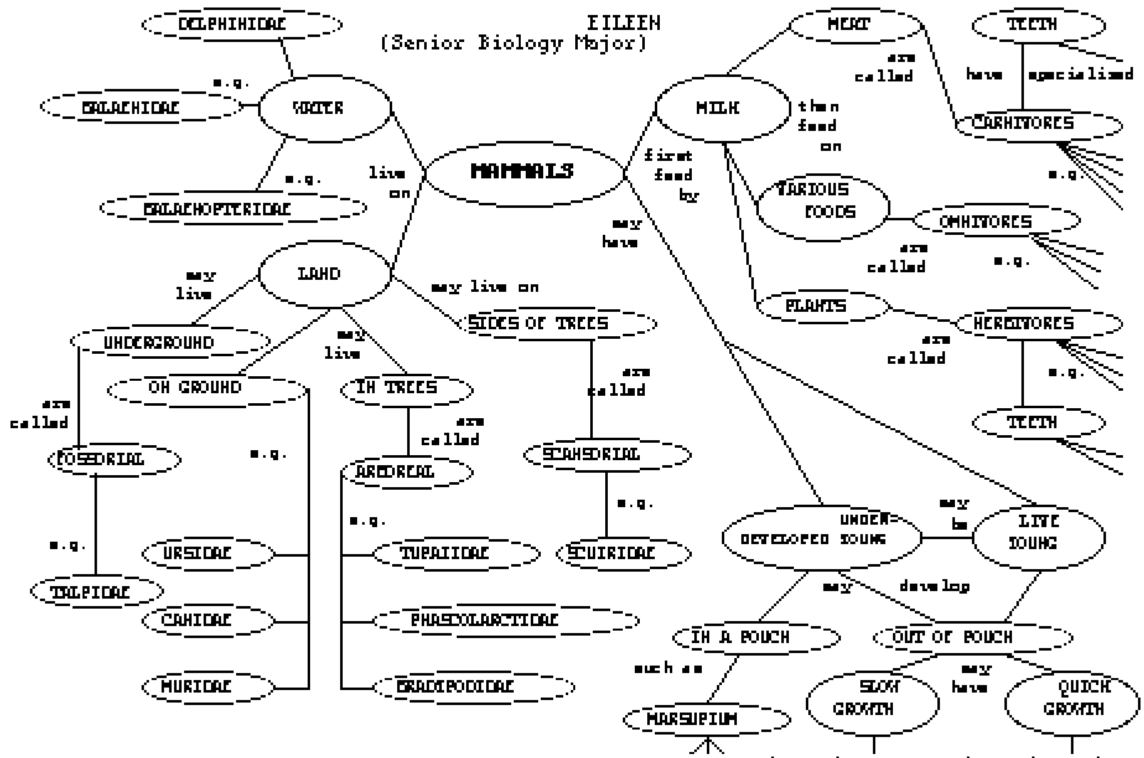
KELLY

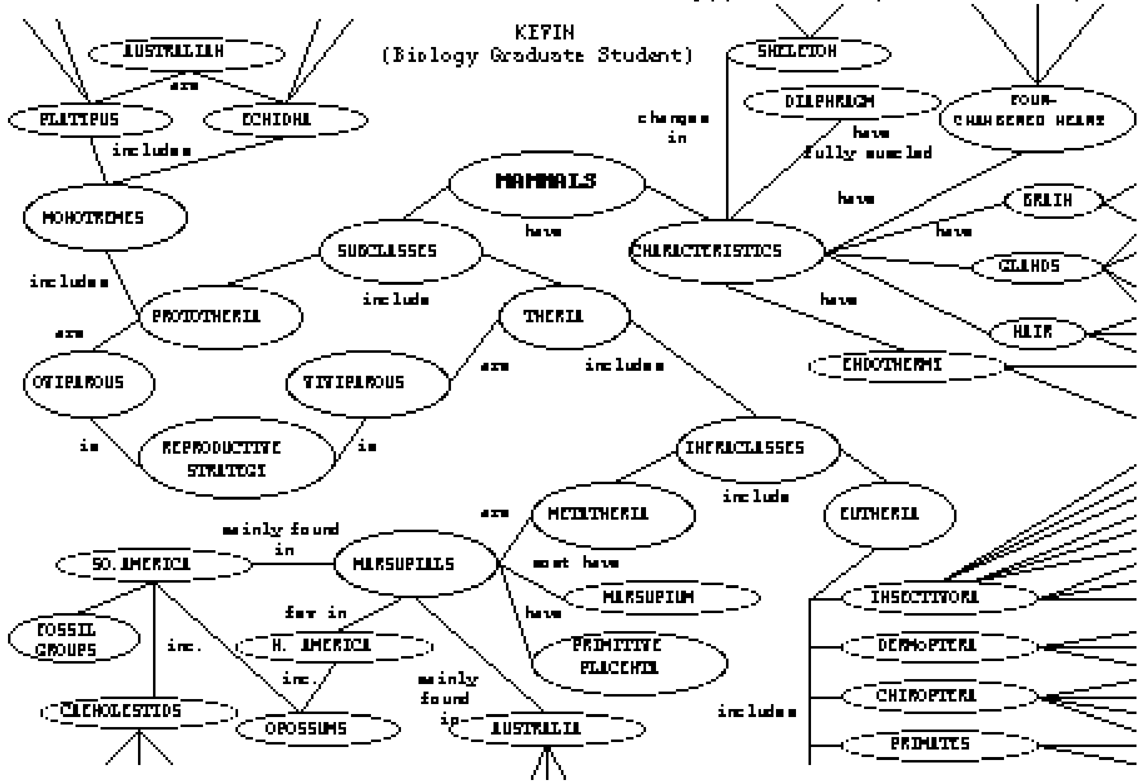
(Freshman Nonscience Major)



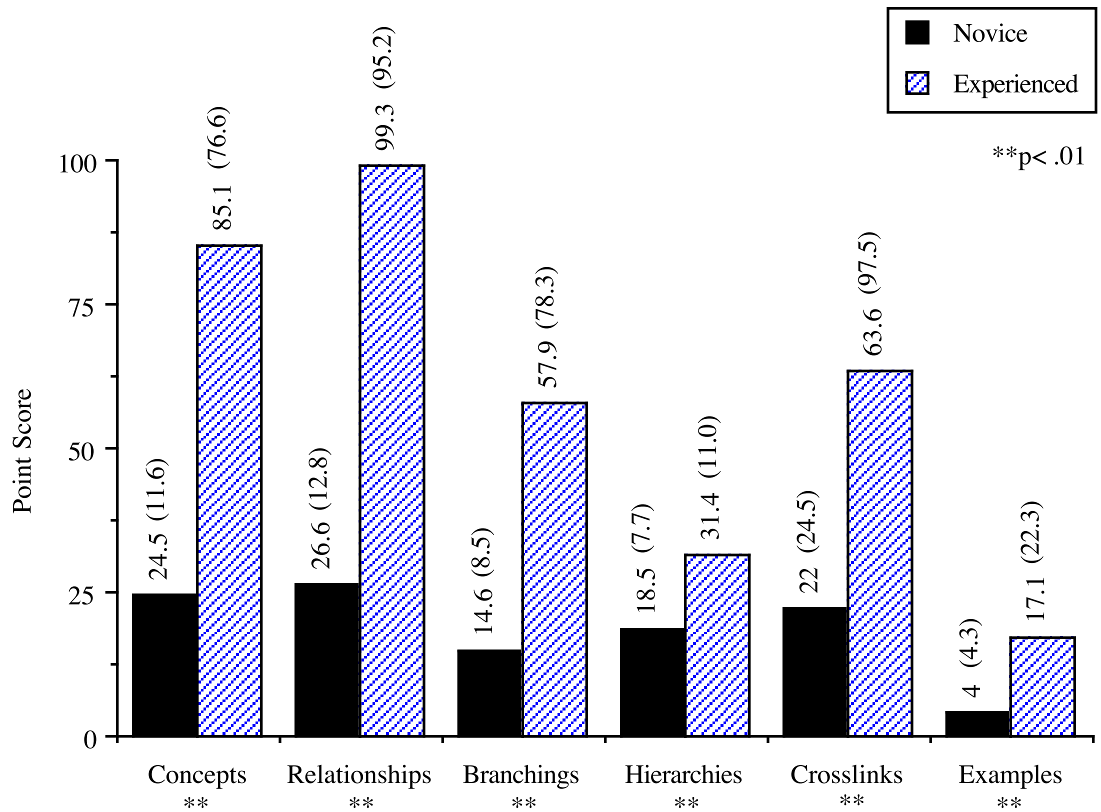
BRIAN
(Sophomore Nonscience Major)



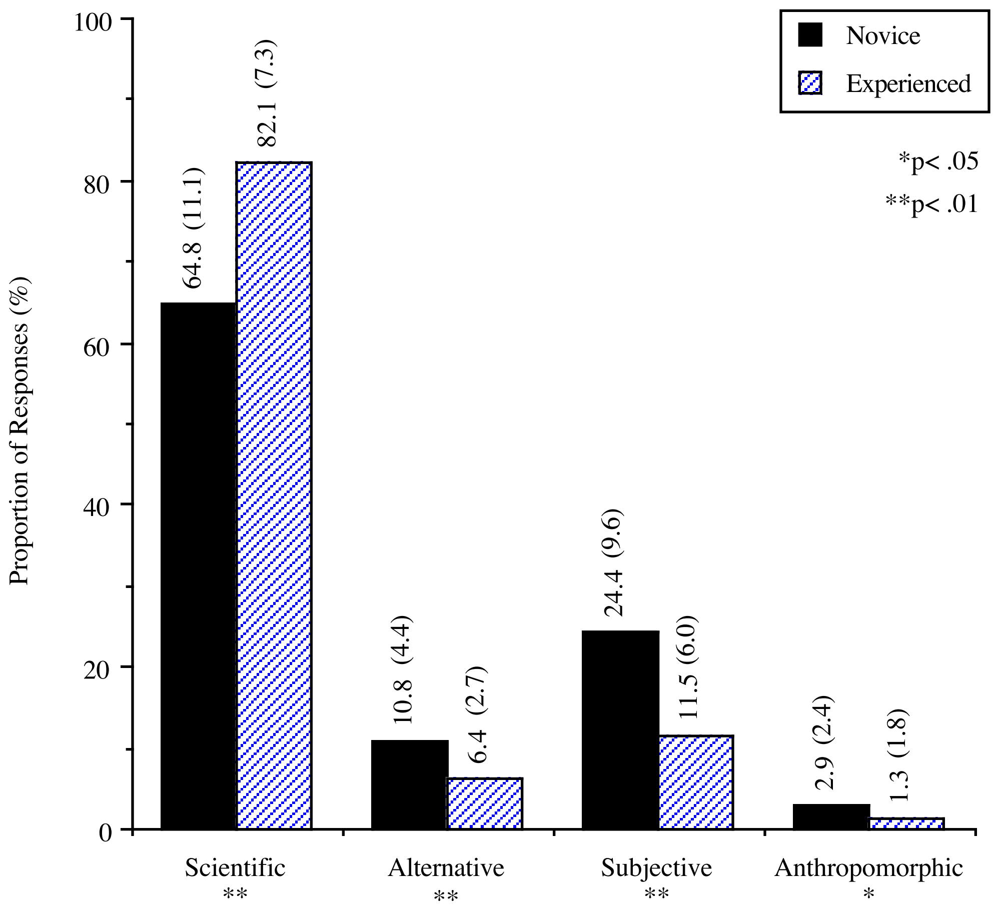

EILEEN
(Senior Biology Major)
DELPHINIDAE
e.g.
BALAENIDAE
WATER
e.g.
BALAENOPTERIDAE
live on
MAMMALS
LAND
may live
UNDERGROUND
ON GROUND
may live
IN TREES
may live on
SIDES OF TREES
are called
FOSSORIAL
e.g.
TALPIDAE
e.g.
URSIDAE
CANIDAE
MURIDAE
are called
ARBOREAL
e.g.
TUPAIIDAE
PHASCOLARCTIDAE
BRADYPODIDAE
are called
SCANSORIAL
e.g.
SCIURIDAE
MEAT
are called
MILK
then feed on
first feed by
VARIOUS FOODS
are called
PLANTS
are called
TEETH
have
specialized
CARNIVORES
e.g.
OMNIVORES
e.g.
HERBIVORES
e.g.
TEETH
may have
UNDER-DEVELOPED YOUNG
may be
LIVE YOUNG
may
develop
IN A POUCH
OUT OF POUCH
such as
MARSUPIUM
may have
SLOW GROWTH
QUICK GROWTH

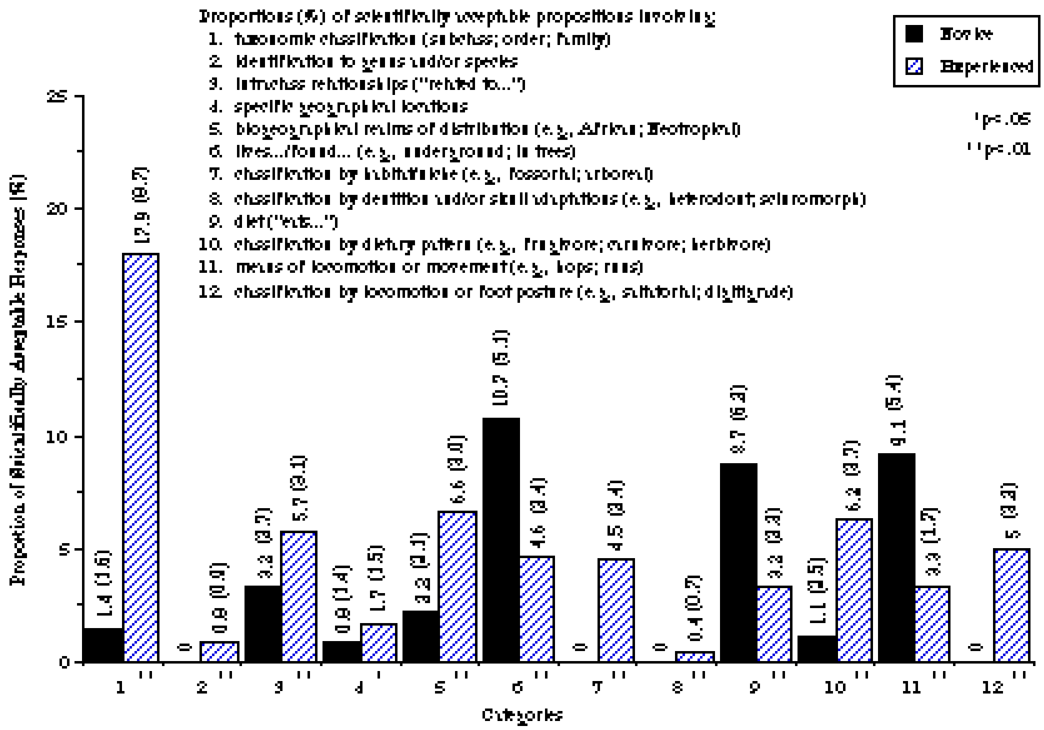

KEVIN
(Biology Graduate Student)
AUSTRALIAN
are
PLATYPUS
ECHIDNA
includes
MONOTREMES
includes
MAMMALS
have
SUBCLASSES
include
PROTOTHERIA
THERIA
are
OVIPAROUS
VIVIPAROUS
are
is
REPRODUCTIVE STRATEGY
is
includes
INFRACLASSES
include
are
METATHERIA
EUTHERIA
mainly found in
SO. AMERICA
MARSUPIALS
most have
MARSUPIUM
have
PRIMITIVE PLACENTA
FOSSIL GROUPS
inc.
few in
N. AMERICA
inc.
CAENOLESTIDS
OPOSSUMS
mainly found in
AUSTRALIA
includes
INSECTIVORA
DERMOPTERA
CHIROPTERA
PRIMATES
changes in
SKELETON
DIAPHRAGM
have fully muscled
FOUR-CHAMBERED HEART
CHARACTERISTICS
have
BRAIN
have
GLANDS
have
HAIR
ENDOTHERMY

CONCEPT MAPPING SCORES

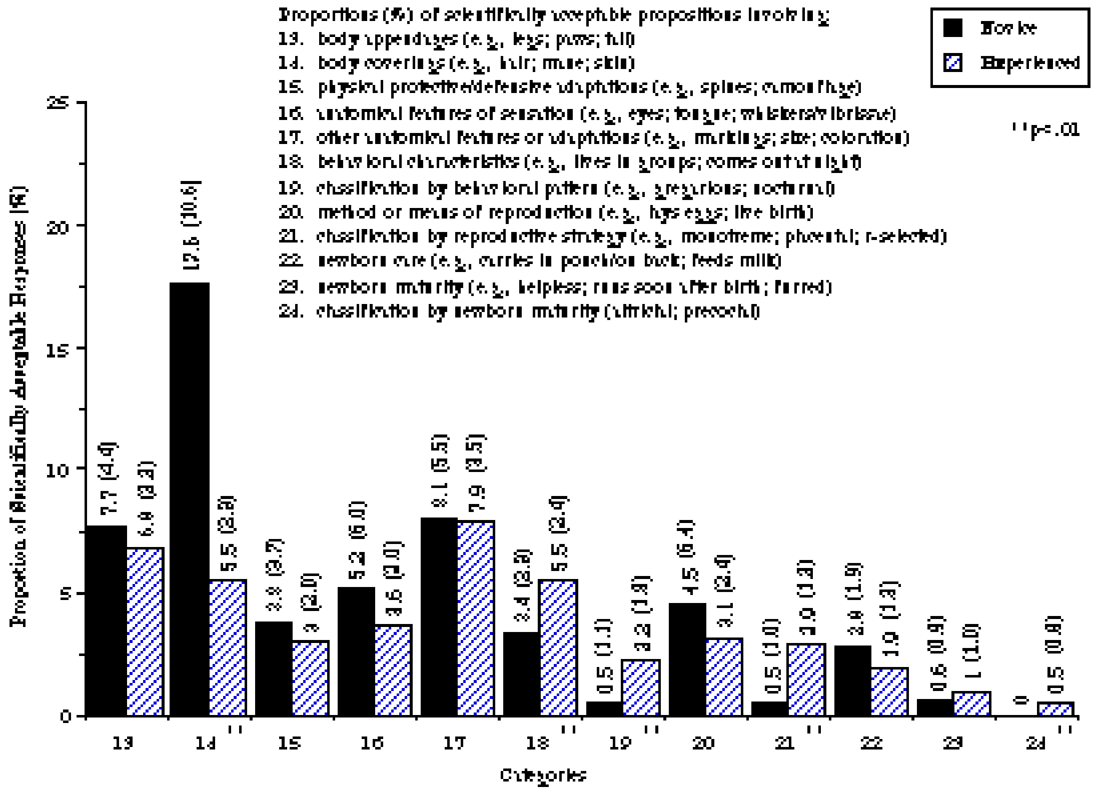


PROPOSITIONS GIVEN BY NOVICE AND EXPERIENCED STUDENTS

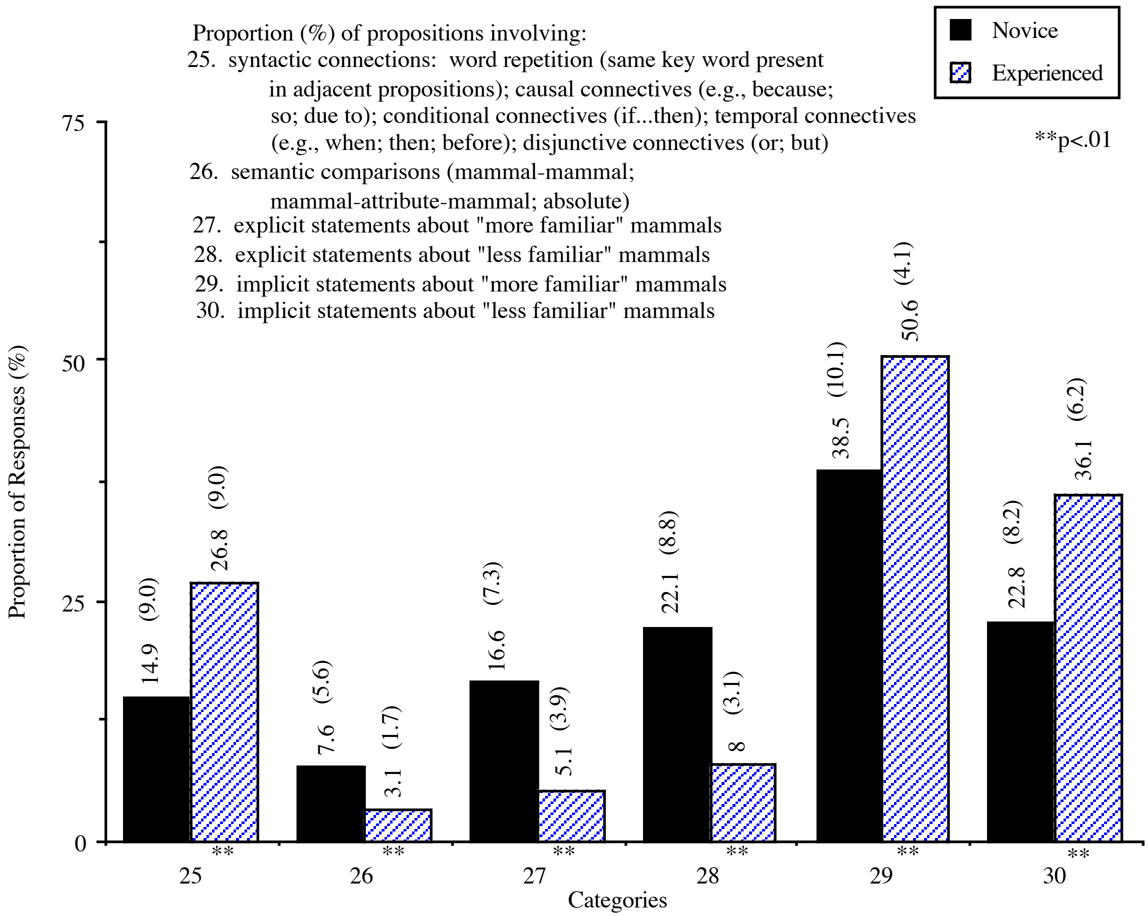



Proportions (%) of scientifically acceptable propositions involving:
1. taxonomic classification (subclass; order; family)
2. identification to genus and/or species
3. intraclass relationships ("related to...")
4. specific geographical locations
5. biogeographical realms of distribution (e.g., African; Neotropical)
6. lives.../found... (e.g., underground; in trees)
7. classification by habitat/niche (e.g., fossorial; arboreal)
8. classification by dentition and/or skull adaptations (e.g., heterodont; sciuromorph)
9. diet ("eats...")
10. classification by dietary pattern (e.g., frugivore; carnivore; herbivore)
11. means of locomotion or movement (e.g., hops; runs)
12. classification by locomotion or foot posture (e.g., saltatorial; digitigrade)
Novice
Experienced
* p<.05
** p<.01
Proportion of Scientifically Acceptable Responses (%)
Categories

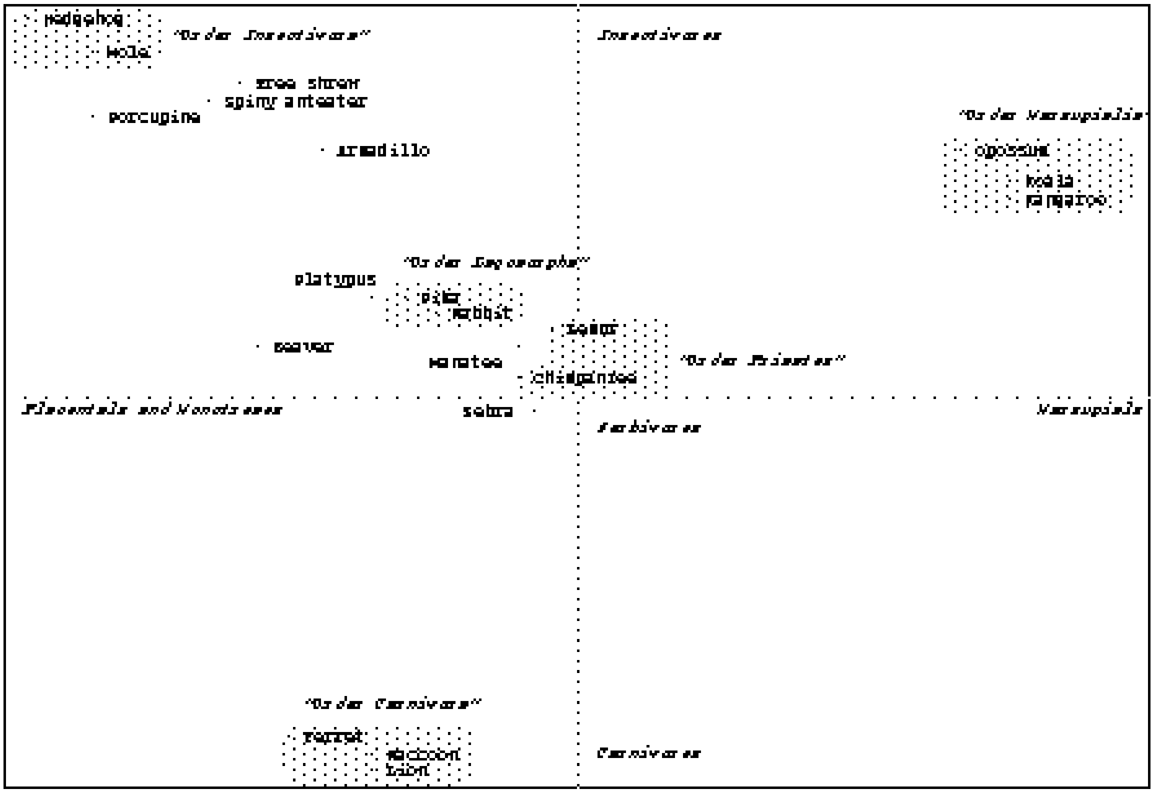
SCIENTIFICALLY ACCEPTABLE PROPOSITIONS BY NOVICE AND EXPERIENCED STUDENTS



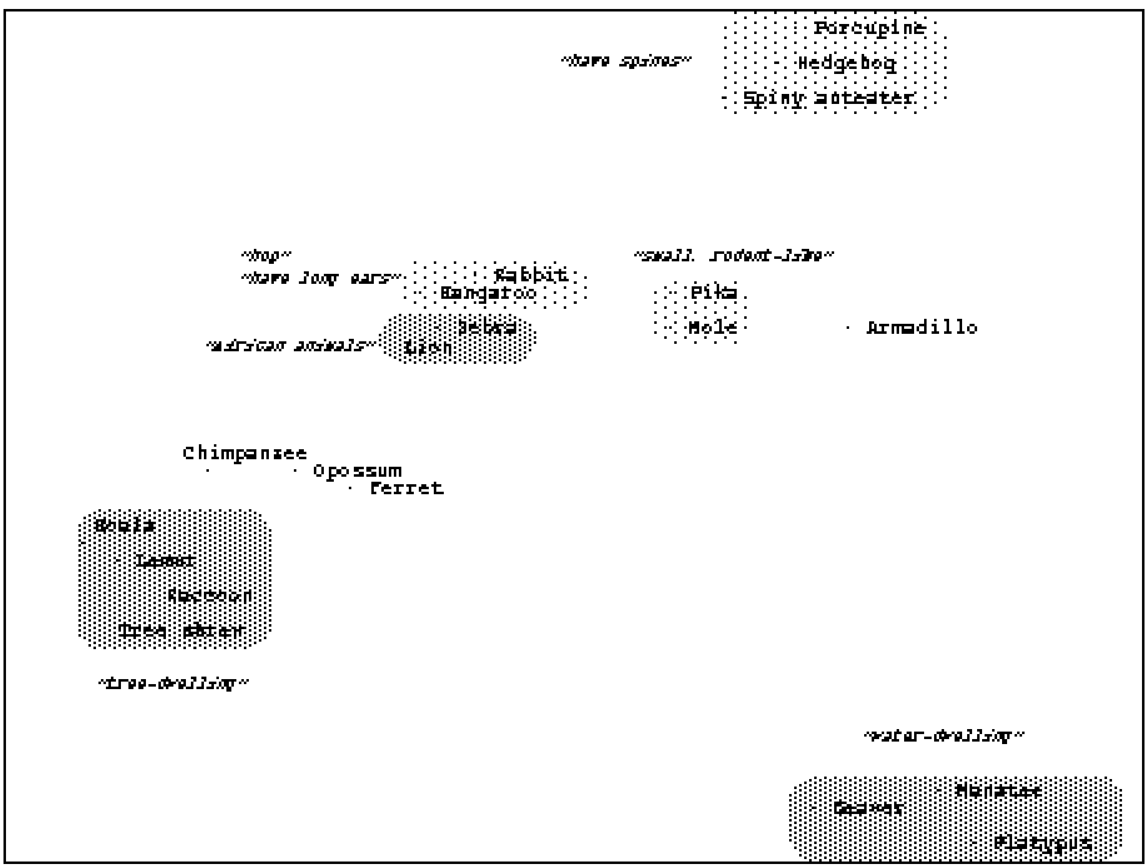
PROPOSITIONS GIVEN BY NOVICE AND EXPERIENCED STUDENTS



EXPERIENCED STUDENTS



NOVICE STUDENTS



SORTING RATIONALE GIVEN BY NOVICE AND EXPERIENCED STUDENTS