Relational complexity has been found to be an effective metric for cognitive tasks. The hypothesis that the greater difficulty and later age of attainment of hierarchical classification as compared to category induction are attributable to differences in structural complexity was tested. Hierarchical classification entails a ternary relation between Categories B, A, and A prime such that A and A prime are included in B. Category induction entails a binary relation between a category and its complement. Forty children, 3 to 6 years old, were assessed on hierarchical classification by property inference between levels (basic-subordinate or subordinate-basic) and on category induction using property inference within levels (basic-basic, subordinate-subordinate). The same hierarchies were used in both tasks, and special care was taken to control for question content. As predicted from relational complexity theory, hierarchical classification was more difficult than category induction, and children older than 5 years succeeded on both tasks, but 3-year-olds succeeded on category induction only. Multiple regression analysis showed that 68% of the age-related variance was accounted for by performance on tasks from other domains that were known to entail the same level of relational complexity. (EMK)
Category Induction and Hierarchical Classification Assessed by Property Inference:

The Influence of Complexity

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Abstract

Hierarchical classification has traditionally been tested by comparing set numerosities in inclusion tasks (more apples or more fruit), whereas category induction has been tested by property inference (whether a property of an instance applies to other instances of that or different categories). Hierarchical classification can be assessed by property inference because of asymmetric relations between levels. Thus properties of a basic level category (fruit) apply to a subordinate (apples) but not vice versa. A common assessment method permits comparison of the tasks. The generally observed greater difficulty of hierarchical classification could be attributed to structural complexity. Hierarchical classification entails a ternary relation between categories, B, A and A' such that A and A' are included in B. Category induction entails a binary relation between a category and its complement. Relational complexity has been found to be an effective metric for cognitive tasks. Forty children aged 3:6-6:0 were assessed on hierarchical classification by property inference between levels (basic-subordinate or subordinate-basic) and on category induction using property inference within levels (basic-basic, subordinate-subordinate). The same hierarchies were used in both tasks, and special care was taken to control for question content. As predicted from relational complexity theory, hierarchical classification was more difficult than category induction, and children over 5 succeeded on both tasks but 3-year olds succeeded on category induction only. Multiple regression analysis showed that 68 % of the age-related variance was accounted for by performance on tasks from other domains that were known to entail the same level of relational complexity.
Category Induction and Hierarchical Classification Assessed by Property Inference:

The Influence of Complexity

Background & Rationale

Hierarchical classification (Inhelder & Piaget, 1964) has traditionally been tested by class inclusion tasks in which the numerosities of classes at different levels of generality are compared (e.g., Are there more apples or more fruit?) Category induction (Gelman & Markman, 1987) has been tested by property inference tasks in which children judge whether a property of an instance generalises to instances of the same category or a different category.

Hierarchical classification can be also assessed by property inference. Correct inferences require recognition of the asymmetry of the relation between categories at different levels of the hierarchy. Properties of a basic level category (fruit) apply to a subordinate category (apples) but the reverse is not necessarily true. A common assessment method (property inference) would permit comparison of hierarchical classification and category induction.

The study tested that hypothesis that the greater difficulty and later age of attainment of hierarchical classification as compared to category induction are attributable to differences in structural complexity. Complexity was assessed in terms of relational complexity which has been found to be an effective metric for cognitive tasks (Halford, Wilson, & Phillips, in press). Children were tested on hierarchical classification using property inference between levels of a hierarchy and on category induction using property inference within levels. They also completed two additional tasks (class inclusion and transitivity) that were known to entail the same level of relational complexity as hierarchical classification.
Relational Complexity metric (Halford, et al., in press)

Relational complexity refers to the arity of relations (i.e., number of arguments or entities related). Each argument corresponds to a dimension and an N-ary relation is a set of points in N-dimensional space. Number of dimensions corresponds to the number of interacting variables that constrain responses or decisions. A relational complexity metric is defined. Unary relations have a single argument as in class membership, dog(fido). Binary relations have 2 arguments as in larger-than(elephant, mouse). Ternary relations have 3 arguments as in addition(2,3,5). Quaternary relations such as proportion have 4 interacting components as in 2/3 = 6/9. Quinary relations entail 5 interacting components.

Processing load increases with complexity, but complexity can be reduced through segmentation and chunking strategies. Normative data suggests that children process unary relations at 1 year, binary relations at 2 years, ternary relations at 5 years, quaternary relations at 11 years (medians).

Complexity analyses

Hierarchical classification entails a ternary relation between 3 categories, B, A and A' such that A and A' are included in B as shown in Figure 1. Property inferences involving instances of categories at different hierarchical levels (between-level property inferences) and comparison of the numerosities of a larger subclass and its superordinate class (more B or more A) each have the complexity of a ternary relation.

Category induction entails a binary relation between categories at the same level of the hierarchy. Given that a property, has bones, applies to a category, cold water fish, does this property apply to instances of a complementary category, sharks, or to another instance of the cold water fish category? Thus within-level property inference and
comparison of the numerosities of two subclasses (more A or more A') each have the complexity of a binary relation as shown in Figure 2.

**Transitivity.** Transitive reasoning is demonstrated when an inference ARC is deduced from premises ARB and BRC, where R is a transitive relation, and A, B, and C are the elements related. Determining the relation between A and C typically involves integrating premises ARB and BRC to construct an ordered triple, ARBRC (Sternberg, 1980; Trabasso, 1975). The ARC inference requires that both premises be considered in the same decision and has the complexity of a ternary relation. Constructing an ordered series by concatenation involves considering one premise at a time and has the complexity of a binary relation.

**Predictions**

*Complexity effects* were predicted on the three tasks. On the property inference task, between-level items (ternary relation) will be more difficult than within-level items (binary relation). On the class inclusion task, numerosity comparisons involving a major subclass and superordinate class (ternary relation) will be more difficult than comparison of subclasses (binary relation). On the transitivity task, ordering based on integration of two premises (ternary relation) will be more difficult than ordering based on a single premise (binary relation).

**Age of Attainment.** On property inference, class inclusion, and transitivity, children over 5 years will perform at above chance level on both binary and ternary relation items. Children under 5 years should succeed on the binary but not the ternary relation items.

**Relation between tasks.** If the difficulty of property inference is due to its relational complexity, property inference should correlate with class inclusion and transitivity tasks whose items also vary in complexity.
Age related variance. If capacity to process complex relations increases with age during childhood, then class inclusion and transitivity should account for age-related variance in property inference.

Method

Participants

Two groups of children participated. The younger group consisted of 18 children aged 3;6 to 4;10 (mean age, 4;1). The older group consisted of 22 children aged 4;11 to 5;11 (mean age, 5;5).

All children completed 3 tasks: property inference, class inclusion and transitivity.

Property Inference Task

The property inference task investigated children’s willingness to make inferences about properties based on category membership. Figure 3 shows the categorical structure on which the inferences were based. At the more general level, there were 2 categories, designated as basic and complementary basic. At the more specific level, there were 2 categories, subordinate and complementary subordinate.

Semantic Hierarchies. Eight different semantic contents were selected to conform to this hierarchical structure. The hierarchies and properties are shown in Table 1. The properties were ones that children would be unlikely have known previously but which they could understand. This was to ensure that responses would be based on inference rather than their prior knowledge.

Question types. Eight questions were generated for each hierarchy. Table 2 shows questions for the cold water fish hierarchy. The between-level (1-4) and within-
level (5-8) questions were similar in terms of presentation format and content but differed in terms of structure.

Between-level questions involved inferences about instances of hierarchically related categories (i.e., at basic and subordinate levels). Questions 1 and 2 referred the same two categories, but the direction of the inference differed. Basic-to-subordinate inferences required Yes responses, whereas subordinate-to-basic inferences required No or Can't tell responses. Correct responses to both questions were required to demonstrate understanding of the asymmetric relation between categories at different levels. Questions 3 and 4 involved inferences based on basic and complementary subordinate categories. These were also jointly scored. Thus the maximum score for the between-level inferences for each semantic hierarchy was 2. For the eight hierarchies, the maximum score was 16.

Within-level questions (5-8) involved inferences about instances of categories at the same level. Questions 5 and 6 referred to basic level categories. Questions 7 and 8 referred to subordinate level categories. For consistency with the between-level inferences, these pairs of questions were also jointly scored. For the eight hierarchies, the maximum score was 16.

Materials. There were 48 pictures depicting the 6 instances of the 8 semantic hierarchies. There were two instances of each basic and subordinate category, and one instance of each complementary category.

Procedure. Children responded to 64 questions, 8 for each semantic hierarchy. The procedure is demonstrated using Questions 1 and 5 for the cold water fish hierarchy.
Question 1: Basic-to-subordinate

This is a cold-water fish  
Category 1 instance presented

This is a salmon    
Category 2 instance presented

A salmon is a type of cold-water fish    
Inter-category relation specified

All cold-water fish have bones    
Property of category 1 stated

Do all salmon have bones? Yes    
Inference question

Question 5: Basic-to-complementary basic

This is a cold-water fish    
Category 1 instance presented

This is a shark    
Category 2 instance presented

A shark is not a cold-water fish.    
Inter-category relation specified

All cold-water fish have bones    
Property of category 1 stated

Do all sharks have bones? No    
Inference question

Class Inclusion Task

Understanding the implications of hierarchical structures was also assessed using Andrews’ (1997) modification of Hodkin’s (1987) class inclusion task.

Materials & Procedure. The six displays contained coloured geometric shapes which formed an inclusion hierarchy. Figure 4 depicts a typical display with three yellow squares and two blue squares. Children responded to three questions per display. Question A required comparison of the two subclasses and involves a binary relation. Question C required comparison of the superordinate class and the major subclass. This requires inclusion reasoning which entails the ternary relation among three classes (squares, yellow things, blue things). Question B was included because Hodkin’s method of estimating and correcting Question C for guessing requires that the number of errors on superordinate-minor subclass comparisons be known.
Scoring. The binary relation score (max = 6) reflected correct responses to Question A. The ternary relation score (max = 6) was computed by deducting the number of errors on Question B (min = 0) from the number of correct responses to Question C (max = 6) (Hodkin, 1987).

Transitivity task

Materials. The premise displays consisted of 4 pairs of coloured squares in which one colour was higher than another (see figure). The 4 pairs together defined a unique vertical ordering of 5 coloured squares in a tower. For the example shown, the correct top-down order is red, blue, green, purple, yellow. More generally, A > B > C > D > E where A is top position and E is bottom. A different assignment of colours to ordinal positions was used on each trial.

Procedure. In the binary relation items, children constructed 2 × 5-square towers, beginning with an internal pair, either BC or CD. Ordering squares B and C, required consideration of a single premise, B above C, and is equivalent to a binary relation. Adding each subsequent square (e.g., D) required consideration of a single premise, C above D. One point was awarded for each correctly ordered initial pair and subsequent square. This yielded a maximum binary relation score of 8.

In the ternary relation items, children predicted which of 2 squares (positions B and D) would be higher up in the tower. Two premises, B above C and C above D must be integrated to form the ordered set, B above C above D, from which B above D can be concluded. As a check on guessing, C was placed after B and D. If the child had integrated BC and CD to conclude B above D, the correct position of C (between B and D) should have been apparent. Credit was given for responses where B, D, and C were placed correctly to yield a ternary relation score (max = 8).
Results & Discussion

Predictions 1 & 2

Table 3 shows the mean number of correct within-level and between-level inferences made by each age group. Between-level inferences were more difficult than within-level inferences, $F(1,38) = 29.64, p < .001$. The same hierarchies were used in both types of inferences, and special care was taken to control for question content and task procedures. The difficulty appears to be due to the structural complexity of the inferences. Between-level inferences required ternary relations, whereas within-level inferences entailed binary relations. Older children performed better than younger children, $F(1,38) = 19.28, p < .001$.

Table 4 shows the mean number of correct responses to items on the class inclusion task made by each age group. There were significant effects of complexity, $F(1,38) = 186.31, p < .001$, and age, $F(1,38) = 22.13, p < .001$ and a significant Age $\times$ Complexity interaction, $F(1,38) = 15.37, p < .001$. Numerosity comparisons involving the superordinate class and major subclass were more difficult than subclass comparison for both age groups, but the effect was greater for younger, $F(1,17) = 169.84, p < .001$ than older children, $F(1,17) = 46.10, p < .001$.

Table 5 shows the mean number of correct responses to transitivity items made by each age group. Ordering based on integration of two premises (ternary relation) was more difficult than ordering based on a single premise (binary relation), $F(1,38) = 181.06, p < .001$. The effect of age did not reach significance, $F(1,38) = 2.79, p = .10$.

Prediction 3

Table 6 shows the intercorrelations between the tasks. All pairwise correlations were significant. This is consistent with our relational complexity analyses which
indicated that high levels of performance on the three tasks require ternary relations to be represented. Class inclusion was more strongly related than transitivity to property inference, Steiger's $t(39) = 2.06, p < .05$, perhaps reflecting the hierarchical structure common to class inclusion and property inference but not transitivity.

Prediction 4

Age was strongly related to property inference performance accounting for .47 ($r^2 = .692$) variance. Age, class inclusion, and transitivity together accounted for .49 of total variance in property inference, Multiple $R = .70$, $F(3, 36) = 11.34, p < .001$. The unique contribution of age was .15 (squared semi-partial correlation). Thus class inclusion and transitivity reduced the contribution of age from .47 to .15, thereby accounting for 68% of age related variance in property inference.

Conclusions

The complexity effects and the similar patterns of success for the older and younger children observed across the 3 tasks are consistent with the predictions of the relational complexity approach. The greater difficulty of items requiring ternary versus binary relations suggest that processing loads increase with the arity of relations. The correlations and regression analyses indicate the existence of a domain general capacity to process relations of increasing complexity. This capacity appears to increase with age during childhood. Children under 5 years processed binary relations, but experienced difficulty with ternary relations. These data are consistent with age norms obtained in other studies (Andrews, 1997). The presence of a domain general factor in no way precludes the influence of domain specific factors, as evidenced in our data by the stronger correlation between tasks that share a common hierarchical structure. The property inference and class inclusion data suggest that the generally observed greater
difficulty and later age of attainment of hierarchical classification over category induction are due to differences in structural complexity.
References


Eight Hierarchical sets containing natural kinds categories and their properties

<table>
<thead>
<tr>
<th>Basic</th>
<th>Property of Basic</th>
<th>Complementary</th>
<th>Subordinate</th>
<th>Property of</th>
<th>Complementary</th>
<th>Property of</th>
</tr>
</thead>
<tbody>
<tr>
<td>bats</td>
<td>use sonar to help</td>
<td>sugar gliders</td>
<td>horseshoe bats</td>
<td>eat insects</td>
<td>vampire bats</td>
<td>eat animal blood</td>
</tr>
<tr>
<td>caterpillars</td>
<td>turn into cocoon</td>
<td>centipede</td>
<td>two-ribbed arcatiit</td>
<td>turn into moth</td>
<td>swallow-tail</td>
<td>turn into butterfly</td>
</tr>
<tr>
<td>cats</td>
<td>climb trees</td>
<td>hyenas</td>
<td>tigers</td>
<td>like swimming</td>
<td>lions</td>
<td>live in prides</td>
</tr>
<tr>
<td>igneous rocks</td>
<td>made in volcanoes</td>
<td>sedimentary rocks</td>
<td>basalt</td>
<td>used to make roads</td>
<td>pumice</td>
<td>used to clean feet</td>
</tr>
<tr>
<td>otters</td>
<td>eat meat</td>
<td>beavers</td>
<td>sea otters</td>
<td>swim in the ocean</td>
<td>Asian otters</td>
<td>live in rivers</td>
</tr>
<tr>
<td>cold-water fish</td>
<td>have bones</td>
<td>sharks</td>
<td>salmon</td>
<td>swims upstream</td>
<td>trout</td>
<td>have dark flesh</td>
</tr>
<tr>
<td>turtles</td>
<td>swim in the sea</td>
<td>tortoises</td>
<td>soft-shell turtles</td>
<td>swim in swamps</td>
<td>leather-back turtles</td>
<td>swim in ocean</td>
</tr>
<tr>
<td>squirrels</td>
<td>gnaw wood</td>
<td>weasels</td>
<td>grey squirrels</td>
<td>live in trees</td>
<td>striped squirrels</td>
<td>live in burrows</td>
</tr>
<tr>
<td>Question types</td>
<td>Example Questions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>--------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Between-level</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Basic to subordinate</td>
<td>Do all salmon have bones? Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Subordinate to basic</td>
<td>Do all coldwater fish swim upstream? No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Basic to complementary-subordinate</td>
<td>Do all trout have bones? Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Complementary-subordinate to basic</td>
<td>Do all coldwater fish have dark flesh? No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Within-level</strong></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>5. Basic to complementary-basic</td>
<td>Do all sharks have bones? No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Basic to basic</td>
<td>Would this cold-water fish have bones? Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Subordinate to complementary-subordinate</td>
<td>Do all trout swim upstream? No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Subordinate to subordinate</td>
<td>Would this salmon swim upstream? Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 3

**Means (SD) for Within-level and Between-level Property Inferences by Age Group (max = 16)**

<table>
<thead>
<tr>
<th>Age group</th>
<th>Within-level</th>
<th>Between-level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Younger (3;6 - 4;10)</td>
<td>5.67*</td>
<td>3.00</td>
</tr>
<tr>
<td></td>
<td>(2.30)</td>
<td>(2.00)</td>
</tr>
<tr>
<td>Older (4;11 - 5;11)</td>
<td>9.14**</td>
<td>7.32**</td>
</tr>
<tr>
<td></td>
<td>(3.72)</td>
<td>(3.59)</td>
</tr>
<tr>
<td>n = 18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>n = 22</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Above chance level, *p < .01; **p < .001
### Table 4

**Means (SD) for Subclass Comparison and Inclusion Questions by Age Group (max = 6)**

<table>
<thead>
<tr>
<th>Age group</th>
<th>Subclass Comparison</th>
<th>Inclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Younger</td>
<td>5.00**</td>
<td>-0.50</td>
</tr>
<tr>
<td></td>
<td>(1.33)</td>
<td>(2.20)</td>
</tr>
<tr>
<td>Older</td>
<td>5.86**</td>
<td>2.82*</td>
</tr>
<tr>
<td></td>
<td>(0.64)</td>
<td>(2.20)</td>
</tr>
</tbody>
</table>

Above chance level, *p < .01; **p < .001
Table 5

Means (SD) for Binary and Ternary Transitivity items by Age Group (max = 8)

<table>
<thead>
<tr>
<th>Age group</th>
<th>Binary</th>
<th>Ternary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Younger</td>
<td>7.11**</td>
<td>1.94</td>
</tr>
<tr>
<td>n = 18</td>
<td>(1.41)</td>
<td>(2.01)</td>
</tr>
<tr>
<td>Older</td>
<td>7.77**</td>
<td>2.70*</td>
</tr>
<tr>
<td>n = 22</td>
<td>(0.69)</td>
<td>(2.51)</td>
</tr>
</tbody>
</table>

Above chance level, *p < .05; **p < .001
Table 6

Correlations among Property Inference, Class Inclusion, Transitivity and Age, with Descriptive Statistics

<table>
<thead>
<tr>
<th>Variables</th>
<th>Property inference</th>
<th>Class inclusion</th>
<th>Transitivity</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property inference $^a$</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class inclusion $^a$</td>
<td>.56**</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transitivity $^a$</td>
<td>.39*</td>
<td>.45**</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>.69**</td>
<td>.70**</td>
<td>.48**</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Means

<table>
<thead>
<tr>
<th></th>
<th>12.95</th>
<th>6.80</th>
<th>9.84</th>
<th>58.15</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD</td>
<td>(6.76)</td>
<td>(3.47)</td>
<td>(2.73)</td>
<td>(9.50)</td>
</tr>
<tr>
<td>N</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>

$p < .01$ ** $p < .001$

$^a$ Binary and ternary items combined
Figure Captions

Figure 1. Classes involved in hierarchical classification.

Figure 2. Classes involved in category induction.

Figure 3. Categorical structure underlying the property inferences.

Figure 4. An example display with relevant questions for the class inclusion task.

Figure 5. An example premise display for the transitivity task.
Included in B

Complements

Included in

A

A'
Complements
A

B

Cold water fish
Have bones

Sharks

Salmon
Swim upstream

Trout
Have dark flesh
Question A. *Are there more yellow things or more blue things?*

Question B. *Are there more squares or more blue things?*

Question C. *Are there more squares or more yellow things?*
Title: CATEGORY INDUCTION AND HIERARCHICAL CLASSIFICATION ASSESSED BY PROPERTY INFERENCE: THE INFLUENCE OF COMPLEXITY

Author(s): GRAEME S. HALFORD, GLENDON ANDREWS, INGELISE JENSEN

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(Rev. 6/96)