Semantic Familiarity, Relevance, and the Development of Deductive Reasoning

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This study examined the developmental progression of deductive reasoning between Grades 6 and 12 and the role of semantic content relevance in the solution of the Wason selection task. A rating procedure was used to establish the degree of relevance between antecedent and consequent clauses of conditional (if . . . , then . . . ) propositions. Results were consistent with the general position that formal deductive reasoning becomes available in adolescence and that relevant propositional content is not a sufficient condition for adequate deductive reasoning performance. High-relevant content enhanced level of performance for those having deductive reasoning competence, and low-relevant content failed to support adequate performance. Findings are interpreted within the distinction between the use of the inference rule competence and the facilitation of relevant semantic content.

A considerable body of contemporary research has demonstrated that the ability to reason deductively undergoes a transformation and a well-defined developmental progression between the ages of approximately 10-11 years and 17-18 years (Bady, 1979; Bucci, 1978; Byrnes & Overton, 1986, 1988; Moshman, 1979; Moshman & Franks, 1986; O'Brien & Overton, 1980, 1982; Overton, Byrnes, & O'Brien, 1985; Overton, Ward, Noveck, Black, & O'Brien, 1987; Pollack, Ward, & Overton, 1988). This same body of research, as well as additional studies (Clement & Falmagne, 1986; Franco & Overton, 1984; Markovits, 1986; Overton, Yauere, & Ward, 1986), supports the position that prior to adolescence, formal deductive reasoning competence is largely unavailable, whereas by late adolescence, individuals demonstrate a high level of competence in solving deductive reasoning problems. These findings do not, however, suggest that available deductive reasoning competence is manifested in all contexts. In fact, earlier research (Gilhooly & Falconer, 1974; Manktelow & Evans, 1979; Wason, 1968), which reported poor reasoning in adults, provided the starting point for empirical explorations of possible factors that moderate the underlying competence that is available to adults (Wason, 1983).

One factor that has proven to be a moderator of successful performance is the semantic content of the reasoning problems. In early research (Bracewell & Hidi, 1974; Van Duyne, 1974), this variable was referred to as thematic or realistic content. Early findings in this area (Wason & Shapiro, 1971; Yachanin & Tweney, 1982) have suggested that when thematic content was used, performance by adults was enhanced. However, later research failed to replicate—or demonstrated only weak support for—this effect (Wason, 1983). Following these efforts, several explanations have been offered to account for this elusive thematic content effect (Cheng & Holyoak, 1985; Griggs, 1983; Overton et al., 1987).

Griggs (1983) suggested that it is the familiar rather than the realistic nature of the content that enhances performance, and this suggestion has been supported in several studies (Griggs & Cox, 1982, 1983). Cheng and Holyoak (1985; Cheng, Holyoak, Nisbett, & Oliver, 1986) have claimed that direct real-world experiences account for the findings. Experiences are represented as inductions from pragmatic activities such as permissions or causations. The inductions form generalized knowledge structures called pragmatic reasoning schema. When similarly structured material is presented at a later time, the schema is elicited, and a richer source of examples is provided from which to draw inferences.

Recently, Overton et al. (1987) reexamined the role of semantic content in deductive reasoning in a series of developmental experiments that assessed performance on a modified version of the Wason selection task. In this task, individuals are given a conditional rule and are required to select conditions that would establish the validity or nonvalidity of the rule. The Overton et al. (1987) experiments demonstrated that regardless of the specific nature of the content, a developmental progression occurs between 4th and 12th grades and deductive competence is largely unavailable before 8th grade. However, familiar semantic content also significantly enhanced performance. The conclusion drawn by these authors was that both logical knowledge (i.e., formal reasoning competence) and world knowledge (i.e., familiar as distinct from abstract semantic content) are necessary but distinct features of adequate logical reasoning performance.

Despite the fact that Griggs (1983), Cheng and Holyoak
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tional and predicate logic, but this logic is ultimately derived
from relevance relations or what Piaget calls
formal level, the meaning systems are integrated into a proposi-
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is identified as the level of formal deductive reasoning. In order
to claim a formal deductive understanding of an implication, it
must be recognized that particular instances of the antecedent
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tional and predicate logic, but this logic is ultimately derived
from relevance relations or what Piaget calls meaningful im-
plication (or signifying implication).

Several predictions follow from considerations of this rele-
vance between antecedent and consequence clauses of condi-
tional propositions. First, because formal deductive systems
represent transformations of relevance relations, meaning
would represent a necessary but not sufficient condition for de-
ductive reasoning. This means that prior to adolescence the re-
levance of conditional propositions should have no effect on cor-
rect deductive reasoning performance. Second, in adolescence,
relevance should support a full deductive understanding of im-
pllication. Finally, for relevant content there should be a devel-
opperational progression in deductive reasoning between child-
hood and late adolescence. That is, the competence to reason
deductively is not systemically available until the adolescent
years, and once available, a variety of real-time procedures may
be required to successfully access and implement the compet-
tence. The concept of systematic availability refers to the fact
that deductive understanding involves a network of inference
rather than being limited to only one or two specific types of
inferences. For example, it may be the case that young children
understand some form of the inference "if p, then q; p; therefore
q;" as a promise or a causal sequence. Evidence of deductive
systemic availability is when this sequence becomes the valid
modus ponens inference, and this in turn becomes a part of a
network of inferences (Overton, 1990).

The selection task is clearly a deductive reasoning task and
one that requires coordination among the permissible and im-
permissible instances that define implication. Because it in-
volves the recognition and coordination of several inference
forms, it is well suited for evaluating the systemic availability
of deductive competence. The selection task also presents the
opportunity to explore procedures that access and implement
competence because the rule can be varied in terms of semantic
content.

Relevance relations can be defined according to several exter-
nal criteria including conventions, causality, and definitions.
However, a more adequate psychological definition would be in
terms of individual judgments concerning the degree of mean-
ing that exists in the relation between the antecedent and conse-
quent clause of a conditional proposition. This rating was the
method used in the present study. In the development of this
measure, clause pairings were rated for the meaningful relation
between them. From these ratings, five conditional statements
were chosen on the basis of the availability of both a high-
and low-relevance value for the antecedent clause of the pairing.
These statements were then used to assess deductive reasoning
of 6th, 9th, and 12th graders on a modified version of the Wason
selection task.

Method

Subjects

A total of 202 5th graders (M = 10 years 11 months, SD = 5.3
months) completed the semantic relevance task. In all, 60 6th graders
(M = 11 years 3 months, SD = 5.5 months), 60 9th graders (M = 14
years 1 month, SD = 6.1 months), and 60 12th graders (M = 17 years 5
months, SD = 5.1 months)—30 boys and 30 girls at each grade level—
completed the selection tasks. All of the subjects were enrolled in

Tasks and Procedure

Semantic relevance task. A set of 100 sentences, presented as two
clauses, were rated according to the degree to which there was a per-
ceived relation between the clauses. Each of 20 antecedent clauses were

(1985), and Overton et al. (1987) all have suggested the impor-
tance of familiar semantic content, neither these nor other in-
vestigations have clearly defined nor independently measured
the nature of the familiarity. The present study addresses the
role of familiarity in the domain of deductive reasoning. Spe-
sifically, we explore the role of semantic content when individu-
als are required to reason deductively with conditional proposi-
tions. Although there are several types of familiarity, a particu-
larly important one concerns the relation between antecedent
and consequent clauses of conditional (i.e., if . . . , then . . . )
propositions that have been used in the bulk of earlier research.
To this point, no investigations have examined developmentally
the role of this familiarity relation—which is called the rele-
ance relation by logicians—in a deductive reasoning task (Mar-
tin, 1987). The present study examines this important rele-
vance relation.

The relation between antecedent and consequent clauses in a
conditional proposition is one of implication. To assert a condi-
tional is to assert that if the antecedent is true, then the conse-
quent is also true. The antecedent implies the consequent. In
genuine implication, as distinct from what is called material
implication, an additional requirement is that there be some
identifiable relation, linkage, connection, or what logicians call
relevance, between the antecedent and consequent (Martin, 1987;
Pieraut-Le Bonniec, 1990; Ricco, 1990). For example, the
conditional "If the moon is made of blue cheese, then the
oceans are full of water" is a true conditional, but it lacks rele-
vance and hence involves only material implication. "If he is a
bachelor, then he is unmarried" is a genuine implication be-
cause of the definitional relevance involved in the fact that be-
ing unmarried is a part of being a bachelor. "If you use your
computer on the job, then it is tax deductible" is a genuine im-
plication whose relevance is conventional in nature.

Relevance between antecedent and consequence then is a
matter of meaning. This relevance (also referred to as entail-
ment) has recently come to assume a major role in Piaget's the-
ory of the development of logical reasoning (Piaget, 1980,
1987a, 1987b; Piaget & García, 1986). In essence, Piaget has
proposed that the operatory logics of concrete and formal oper-
ational thought emerge out of, and are transformations of,
meaning systems that the child develops in the sensorimotor
and preoperational periods. The process continues and ulti-
mately leads to a level at which the acquired system can be char-
acterized as a relatively complete logical competence. This level
is identified as the level of formal deductive reasoning. In order
to claim a formal deductive understanding of an implication, it
must be recognized that particular instances of the antecedent
and consequence clauses of the sentence are permissible, that
other instances are not permissible, and that still others are in-
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Table 1
Mean Ratings of Relevance for Conditional Statements Obtained on the Semantic Relevance Task

<table>
<thead>
<tr>
<th>Statement</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>A person is drinking beer</td>
<td>4.50</td>
<td>0.97</td>
</tr>
<tr>
<td>The person is 21 years of age</td>
<td>1.30</td>
<td>0.80</td>
</tr>
<tr>
<td>A student strikes a teacher</td>
<td>4.71</td>
<td>0.81</td>
</tr>
<tr>
<td>The alarm goes off</td>
<td>1.87</td>
<td>1.14</td>
</tr>
<tr>
<td>You will be punished</td>
<td>4.50</td>
<td>1.04</td>
</tr>
<tr>
<td>You are wearing sneakers</td>
<td>2.48</td>
<td>1.22</td>
</tr>
<tr>
<td>A person is driving a motor vehicle</td>
<td>4.17</td>
<td>1.21</td>
</tr>
<tr>
<td>The person is a school teacher</td>
<td>2.48</td>
<td>1.49</td>
</tr>
<tr>
<td>A person is retired from work</td>
<td>4.11</td>
<td>1.15</td>
</tr>
<tr>
<td>The house is for sale</td>
<td>1.97</td>
<td>1.23</td>
</tr>
</tbody>
</table>

Note. Ratings were on a scale of 1 to 5, from low to high relevance.

Results

To assess developmental differences in reasoning ability, a 3 × 2 × 5 (Grade × Relevance × Problems) analysis of variance (ANOVA), with repeated measures on the last factor, was computed using the complete falsification solution as the dependent measure. This analysis revealed significant main effects for grade, F(2, 168) = 25.24, p < .001; relevance, F(1, 168) = 33.68, p < .001; and problem, F(4, 672) = 8.08, p < .01. There were also significant interactions for Grade × Relevance, F(2, 168) = 5.92, p < .01, and Problem × Relevance, F(4, 672) = 4.67, p < .001. No other interactions were significant.

The developmental effects are considered first. The facilitation effects provided by relevant content are evident in the significant Grade × Relevance interaction. The means of this interaction are shown in Figure 1. The major developmental hypothesis of the study was that, for the relevant content, there would be a developmental progression between 6th and 12th grades. The Newman-Keuls analysis of this interaction supported this prediction, indicating that for high-relevant content, the 12th-grade students selected the complete falsification solu-
tion significantly more often than did the younger students, and the 9th-grade students also performed better than did the 6th-grade students. For the low-relevant content, the 12th-grade students selected the complete falsification solution more frequently than did both the 6th- and 9th-grade students.

The within-grade comparisons showed that at the 6th and 9th grades, students' performance on low- and high-relevant problems did not differ. At the 12th grade, students performed better on high-relevant problems than on low-relevant problems. These findings support the position that relevant content is not sufficient condition for adequate logical reasoning. If relevance were sufficient for logical reasoning, than the low-relevant and high-relevant differences should have been present at all grades. It should have been particularly evident at the 6th grade, inasmuch as relevance was standardized on 5th graders and 6th grade is closest to 5th grade. The developmental differences found in both the high- and low-relevant content conditions support the claim that there is a systematic age-related increase in reasoning performance.

Another measure used to assess whether an individual possesses a formal logical competence is the extent to which the individual is consistent in presenting logical solutions (Overton et al., 1987) across problems. On the basis of earlier research, a criterion of correct solution of at least three of the five high-relevant problems was set for an individual to be designated as a formal deductive reasoner. Expressed as percentages of total number of subjects at each grade level (N = 30), this criterion yielded the following: 6th grade, 16%; 9th grade, 56%; and 12th grade, 80%. A test for the difference between proportions indicated that the 12th and 9th grades contained more formal deductive reasoners than the 6th grade (z = 4.96 and 3.22, respectively), and the 12th grade contained more formal reasoners than the 9th grade (z = 1.99, p < .05). This finding is highly consistent with results reported in the three Overton et al. (1987) experiments. Figure 2 presents the percentage of subjects who performed at a formal level at each age across the three investigations of the Overton et al. (1987) study and across the present investigation.

The specific role of content was examined through the significant Problem × Relevance interaction found in the ANOVA of the complete falsification solution scores. The means are presented in Table 2. A within-problem analysis of this interaction revealed that, with the exception of the school suspension problem, subjects gave the correct response more often when the problem was presented with high-relevant content than when presented with low-relevant content.

Paired comparisons of the problems within the high-relevant condition revealed that subjects gave the correct response more often on the drinking age and motor vehicle problems (M = .64 and .57, respectively) than on the other three problems (retirement, M = .43, halls, M = .36, and school suspension, M = .33). No differences were found in either set of problems. It is of interest to note that both the drinking age and motor vehicle problems correspond most closely to permission schemata. A within-relevance analysis of the five problems for the low-relevant condition showed that subjects gave the correct response more often on the drinking age problem (M = .34) than on the motor vehicle problem (M = .17). No other differences in this condition were significant.

Figure 1. Percentage of logical correct (p, ¬q) falsification solution at each grade for high- and low-relevant conditions.

Figure 2. Percentage of subjects at each grade attaining the criterion for formal reasoning (at least 3 of 5 problems) for Overton, Ward, Noveck, Black, and O'Brien (1987) and the present study.
The task (Wason, 1983).

There were 16 possible selection and consequent clauses is an important factor in determining defined in terms of the relevance relation between antecedent and consequent clauses. The findings of the present research, to-gether with other contemporary findings (Bady, 1979; Moshman & Franks, 1986; O'Brien & Overton, 1980, 1982; Overton, Byrnes & O'Brien, 1985; Overton et al., 1987; Pollack et al., 1988). Prior to the availability of this competence, performance is poor regardless of the relevance of propositional content. At Grade 6, subjects performed poorly under both high- and low-relevant content conditions. When subjects were categorized as formal reasoners, only 16% of the 6th graders fell in this category. On the other hand, there was a clear developmental progression between the 6th and 12th grades. At the 12th-grade level, 80% of the subjects were categorized as formal reasoners.

The findings also support the position that familiarity of content defined in terms of the relevance relation between antecedent and consequent clauses is an important factor in determining logical reasoning performance. It seems clear, however, that relevance operates to facilitate deductive reasoning when systematically available and is not a sufficient condition for deductive reasoning (Overton, 1990; Overton et al., 1987). High-relevant content enhances level of performance for those having formal deductive reasoning competence, whereas low-relevant content fails to support adequate performance. At the 6th grade, logical solutions were meager, regardless of relevance of propositional content. At Grades 9 and 12, low-relevant content continues to result in poor performance. However, for the high-relevant content condition, performance improves significantly from Grades 6 to 12, and for Grades 9 and 12, 56% and 80% of these subjects, respectively, performed at a level of formal deductive reasoning.

Any sufficiency claim (Griggs, 1983) was also weakened by having the ratings completed by a group (5th graders) younger than any age group participating in the selection task phase of this research. If relevance were sufficient for adequate performance, then the 6th graders, being closest in age to the raters, should have benefited at least as much as the other grades from the relevant content. Again, there was no evidence to support this position. Sixth graders performed equally poorly on both high- and low-relevant content problems.

The semantic content effects found in the present study extend the findings reported by Overton et al. (1987) and clarify the elusive thematic effects reported in earlier work (e.g., Bracewell & Hidi, 1974; Griggs & Cox, 1982; Wason & Shapiro, 1971). None of the previous research that reported a positive performance effect due to the substitution of thematic semantic content for abstract content had introduced any independent determination of what constituted thematic. For example, Cheng et al. (1986, Experiment 1) reported a significant difference between two permission schemata problems and credited this finding to a “presumed” difference in familiarity. However, no measure of familiarity was introduced. Although the pragmatic approach has demonstrated a facilitative effect of semantic content, it has not furthered a general account of deductive reasoning (Braine, 1990).

In conclusion, performance on the selection task and other deductive reasoning tasks appears to be the result of an interaction between the development of a logical competence and content effects as measured by relevance between antecedent and consequent clauses. The findings of the present research, together with other contemporary findings (Bady, 1979; Moshman, 1979; O'Brien & Overton, 1980, 1982; Overton et al., 1985, 1987), support the position that the development of propositional and predicate logical knowledge is a necessary prerequisite for adequate and consistent performance on formal reasoning tasks and that this knowledge is not available before adolescence. The semantic content effects found support the distinction that the inference rule competence needed to solve the problem exists separately from problem representation. Therefore, the results are consistent with the notion that relevant semantic content facilitates logical reasoning if the necessary competence is present.

### References


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