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HUMAN REASONING IS BOTH LOGICAL AND PRAGMATIC

Human nature, viewed from the perspective of the classical Greek philosophers, includes a rational capacity that allows for mathematical and logical thought. Indeed, for Aristotle such rationality is the distinctively human characteristic. This view has been shared throughout most of Western intellectual history (the debate between the rationalists and the empiricists concerns not whether people have logical and mathematical knowledge, but how they come to have it). However, perhaps as a result of the industrial revolution, much of 20th century thought has not shared this view. Learning theorists, for example, see human nature as non-logical, and the psychoanalytic perspective sees human nature as basically irrational. Nonetheless, as Henle (1962) noted, this change in perspective was not the result of new empirical evidence — people have always made some logically valid inferences as well as some invalid ones.

Over the past two decades, several influential investigators have argued against any significant role for a logical or mathematical competence, and they have provided empirically based arguments. Prominent among these are several authors working with the Wason selection task (Wason, 1966, 1968), e.g., Evans (1982), and Cheng and her colleagues (Cheng & Holyoak, 1985, 1989; Cheng, Holyoak, Nisbett, & Oliver, 1986; Holland,

Holyoak, Nisbett, & Thagard, 1986). These authors emphasize the influence of the content of the connected propositions. Evans (1982) concludes that "such competence, on the basis of evidence from reasoning experiments, is surprisingly — no doubt to some — depressingly lacking. All the evidence points to content-dependent thought processes on these tasks" (p. 233). Cheng *et al.* (1986) speak of their "negative conclusion" (p. 318) concerning a mental logic, and propose that reasoning typically uses rules defined in terms of classes of goals and contents. Another widely cited set of studies concerns work on probabilistic judgments, e.g., Tversky and Kahneman (1982, 1983), who have argued that people typically do not use normative rules for probability, but rely on the content-dependent availability or representativeness of exemplars in long-term memory.

We follow the classical view that human reasoning includes a rational competence that makes possible logical and mathematical thought. This competence is, we believe, the outcome of an evolutionary history, and it equips humans to integrate information coming in from various sources or at different times. As such, we believe that this competence is not merely symbol manipulation, but is profoundly intentional, i.e, concerned with things and events in the world, and embedded within a pragmatic architecture concerned with setting and obtaining goals and understanding other people's goals (see Macnamara, 1986, for a detailed discussion).

Because reasoning is intentional and pragmatic, the interests of people engaged in ordinary reasoning are not always identical to those of professional logicians. For example, in standard logic the central issue is ensuring the validity of arguments, and an argument is valid unless its premises taken together can be true while its conclusion is false. However, in ordinary reasoning people are more likely to be concerned with the soundness of an argument, i.e., ensuring that if an argument's premises are true, then so is its conclusion. The difference is manifest when one considers that in standard logic, any argument is valid when its premises

are contradictory or epistemically false. In ordinary reasoning, nothing follows from contradictory or false premises except that some mistake has been made (see Braine & O'Brien, 1991, for a discussion of deliberately counterfactual arguments).

Subjects do not usually play metalogician to their own thinking, and thus often are unaware of many potential uses of their logic. For example, if a disjunction *p* or *q* is true, then at least one of its disjuncts must be true, i.e., either *p* is true or *q* is true (this holds both for exclusive and inclusive interpretations). Suppose that under the supposition of *p*, as well as under the supposition of *q*, *r* is derivable. It follows that *r* must be the case. Although we do not know which of the two disjuncts is true, we can assert *r*. This metalogical analysis, following from the meaning of *or*, shows that a general strategy for reasoning from disjunctions is sound; unless one is metalogically reflective, however, knowledge about the meaning of disjunction, by itself, does not reveal the reasoning strategy — logic competence does not ensure that people become aware of the implications of their knowledge.

Ordinary reasoning also differs from systems found in standard logic in that a single line of reasoning can include inferences coming from a variety of processes, i.e., inductive, analogical, based on a script or scenario — and the output of an inference generating process does not necessarily come marked with the sort of process that generated it.

In sum, we claim that logical and mathematical reasoning is made possible by an underlying competence, and that those who have argued against any significant role for competence have overlooked the bioevolutionary context of such competence, i.e., that it is intentional and pragmatic. If one equates errors on reasoning tasks with a lack of competence, then one is bound to conclude that people lack competence. The classical philosophers were not naive — they knew that people often make reasoning errors, but they did not interpret this to mean that people are not capable of rational thought. In general, we believe that errors on

reasoning problems stem from (a) a lack of sophistication with reasoning strategies that follow from metalogical analysis, and (b) the application of pragmatic principles to problems that violate pragmatic principles.

In the first section of this paper we describe a competence model for reasoning with propositional-logic particles, and describe some evidence that supports the model. In the second section we address the strength of the case by critics of a role for competence. We conclude that their claim is weak. In the third section we provide a discussion of text comprehension as a case study of how a research program can integrate propositional-logic inferences with other pragmatic inferences to provide a coherent integration of information.

I. A Model for Reasoning with Propositional-logic Connectives

What should a theory of reasoning with propositional-logic particles accomplish? Consider the following two scenarios:

(1) Professor Moriarty's desk lamp was not working. He decided that the problem was either the fuse, the bulb, or the switch. He replaced the fuse and the bulb with ones that he knew worked, and the lamp still failed. "So," he decided, "the problem must be the switch."

(2) Sherlock Holmes knew that the barn had a watchdog, and that if the burglar had been a stranger, the dog would have barked. However, the dog did not bark. "So," Holmes told Dr. Watson, "the burglar could not have been a stranger."

What went into these two lines of thinking? To understand them, either from the perspective of the reader or of the protagonists, one needs to retrieve three sorts of knowledge from long-term memory: knowledge of the content, e.g., about desk lamps or watchdogs, knowledge about the meaning of the logical particles, e.g., *or*, *if*, and *not*, and knowledge about reasoning strategies, e.g., seeking to eliminate alternatives, seeking to

discover a contradiction under a supposition. What role does logic play? Logic does not provide the premises — real-world knowledge does. Nor does logic tell Holmes to consider what would have happened under the supposition that the burglar was a stranger — his well-practiced strategic skills do this.

Logic does sanction the conclusions drawn: Dr. Moriarty was correct, given his assumptions, that the switch was responsible; Holmes was correct, given his assumptions, that the burglar could not have been a stranger. These conclusions follow, in (1) because the falsity of the first two disjuncts ensures the truth of the third, and in (2) because a contradiction under a supposition, by *reductio ad absurdum*, falsifies the supposition. Note that knowledge about desk lamps, watchdogs, and burglars, by itself, does not warrant these inferences.

In case one might think that information about alternatives, or conditionals, or other logical connectives, is always obtainable entirely from knowledge about content, e.g., desk lamps or watchdogs, and does not require a logic that is content independent, consider the following three reasoning problems, about some letters on an imaginary blackboard: the first presents as a premise *There is a P or a Q*, the second *There is a P if there is a Q*, and the third *There is both a P and a Q*. Each has as a second premise *There is not a P*. On the first problem one would conclude that *There is a Q*, on the second that *There is not a Q*, and on the third that nothing follows, except perhaps that the experimenter has made some sort of error. Note that the only information that distinguishes the three problems is the use of *or*, *if*, or *and* in the first premise. Clearly, these particles convey logical information that is independent of the content of the propositions they connect in any particular case.

Our approach has three parts. The first is a set of inference schemas that allow inferences to be made from the information conveyed by such logic particles in natural language as *if*, *and*, *not*, and *or* in English. This part of the model provides the basic competence for making logical judgments.

These schemas are described in detail elsewhere (e.g., Braine, 1990; Braine, Reiser, & Rumain, 1984; Lea, O'Brien, Fisch, Noveck, and Braine, 1990), and so we do not provide a detailed discussion here. We shall describe the logical schemas pertaining to conditionals, however, because our discussion below of the critics of a role for competence focuses on reasoning tasks with conditional connectives (see O'Brien, 1987, in press, for a detailed discussion of the logic of conditionals).

Two inference schemas have been viewed by logicians as essential to conditionals. The first, *modus ponens*, holds that given *if p then q* and *p* one can assert *q*. The second essential inference schema for conditionals is a *schema for conditional proof*, which holds that to derive or evaluate *if p then q*, first suppose *p*; for any proposition *q* that follows from the supposition *p*, taken together with other given information, one can assert *if p then q*. Our description of the schema for conditional proof differs from that found in standard-logic systems. First, as a special case of our general principle that a variety of sorts of inferences can cohabit in a single line of inference, *q* might be derivable in a variety of ways, e.g., from real-world knowledge, such as that structured in a script. Second, when *p* is supposed, it sets up a context of reasoning in which propositions incompatible with the supposition become inadmissible for use (even when they are true) for so long as the supposition continues to be made. This differs from standard logic, which does not have this constraint. This is, we believe, why people find the so-called paradoxes of material implication paradoxical. Note that in standard logic, given that *p* is true one can derive *If not p then p*, whereas in our model the supposition of *not p* rules out appeal to the truth of *p*. Further, unlike standard logic, when the supposition of *p* together with other given information leads to the falsity of *q*, the conditional *if p then q* is judged to be false (in standard logic, one can infer only that the conditional or its antecedent is false; see Braine & O'Brien, 1991, for a detailed discussion of the differences between this model for *if* and the conditional of standard logic.) Thus, although our

model claims that people have a sound logic for *if*, their understanding is not the same as that found in standard logic.

Two other inference forms for conditionals are sanctioned in standard logic. One, *modus tollens*, holds that given *if p then q* and *not-q*, one can assert *not-p*. The other, the *reductio ad absurdum*, holds that when the supposition of *p*, taken together with other given information, leads to a contradiction, one can conclude that *not-p*. Whereas the model claims that modus ponens and the schema for conditional proof are basic inferences for human reasoners, *modus tollens* and *reductio ad absurdum* arguments are specialized and not always available.

The second part of our approach is a reasoning program that applies the inference schemas. Braine *et al.* (1984) described both a direct reasoning routine and an indirect reasoning routine. The direct routine operates spontaneously to draw inferences from given information, and is claimed to be universally available. The indirect routine is available to many undergraduate subjects, but is in no wise universally available. The indirect routine probably requires special effort or training, or is limited to certain sorts of materials or contexts. The indirect routine is required for complex reasoning to construct lemmas or set up a supposition as the basis for a reductio. The difference between direct and indirect reasoning is illustrated in arguments (1) and (2) above; Moriarty's inference does not surprise us because the disjunction elimination is accomplished through the direct reasoning routine, whereas Holmes's reasoning impresses us because the reductio requires the more sophisticated indirect routine. The difference between the two scenarios is not in basic competence, but in strategic sophistication. From our perspective, an unskilled reasoner is not necessarily an incompetent reasoner.

The third part of our approach is a set of independently motivated pragmatic comprehension principles. The inference schemas and the reasoning program are applied to propositions as interpreted, and not to the surface-structure presentation of the stimuli. Thus, the content of presented

propositions affects how they are construed. In general, an interpretation that is plausible, given someone's knowledge of the situation, will be preferred to one that is implausible (see Bever, 1970). For example, children interpret *If I put up my umbrella it starts to rain* to mean *I put up my umbrella if it starts to rain* (Emerson, 1980; Emerson & Gekoski, 1980). Semantic plausibility is preferred over surface-structure neighborhood relations in determining what a proposition means. The real-world knowledge used in determining plausibility includes not only factual information, but knowledge organized by structures such as scripts and story grammars (which we discuss below in the section concerning text comprehension).

In part, plausible intrepretations are guided by Gricean cooperative principles (see Braine & O'Brien, 1991; Politzer, 1986, for more detailed discussions). Speakers attempt to be as truthful, as relevant, and as clear as they can be, and listeners assume that this is what speakers are doing. The cooperative principles lead to many non-necessary inferences, or *conversational implicatures*. For example, Geis and Zwicky (1971) have argued that *if p then q* invites the inference that *if not-p then not-q*, e.g., *If you mow the lawn I'll give you five dollars* invites the inference that *If you don't mow the lawn I'll not give you the five dollars*. Geis and Zwicky, and Fillenbaum (1977), claimed that such *invited inferences* are made unless people have some reason to believe them inappropriate, e.g., it is your grandfather who made the conditional promise, and he always gives you five dollars, whether or not you mow the lawn.

Listeners do not always understand speakers, and in such cases listeners are forced to rely on pragmatic principles to construct a plausible interpretation (e.g., Sperber & Wilson, 1986). As we shall argue below, when subjects are presented with a complex reasoning problem, they will apply pragmatic principles in an attempt to discover what the experimenter is requiring of them. When an experimental task provides pragmatically misleading cues, subjects are apt to take the bait; when an experimental

task provides pragmatically appropriate cues, appropriate performance is apt to be facilitated.

What evidence is there for the competence model? Several studies have investigated specific predictions of the model. These studies have presented problems with pragmatically neutral content, e.g., referring to letters on an imaginary blackboard, or to toy animals and fruits in a box. The problems present premises about what is on the blackboard or in the box, and require subjects either to assess a given conclusion or to write down everything that can be inferred from the premises. Braine *et al.* (1984) found that the model predicts quite well which conclusions will be accepted, which problems will be difficult, how subjects will perceive relative problem difficulty, and response latencies. Braine, Noveck, Samuels, Fisch, Lea, and O'Brien (1990) and Lea *et al.* (1990) found that the model predicts which propositions will be written down, and the order in which they are written down. O'Brien and Braine (1990) found that children as young as 7-year olds make the predicted responses on conditional-proof problems, i.e., problems with *if* conclusions to be evaluated. Given the neutral content of the problems in these studies, it is difficult to see how these performances could be accounted for on the basis of content-bound inferential processes. Further, no other content-free model that we know of could account for these data. Clearly, the inference-schema models provided in standard-logic textbooks would not account for them, for according to standard logic there are infinitely many inferences that could be drawn from any set of premises. We believe that our model provides a reasonable hypothesis for a reasoning competence for problems with propositional-logic connectives.

II. Criticisms of Competence

We discuss three areas of literature in which prominent critics have argued that neither logical nor mathematical competence plays any

significant role in ordinary human reasoning. The discussion is not meant to be exhaustive, but rather to be representative of criticisms of a role for a mental logic. First, we address work done with the Wason selection task, particularly studies concerning content effects and claims that reasoning typically depends on content-dependent rules. Second, we address a developmental literature that argues against a logical competence for reasoning with conditionals before adolescence. This literature largely is inspired by the Piagetian claim that formal logical competence requires a formal-operational structure that is absent until adolescence. Third, we look at work on probabilistic judgments with the Linda problem by Tversky and Kahneman (1982, 1983) concerning the conjunction fallacy. Although we do not propose a competence model for such judgments, we think that people should realize that the probability of something being a member of a subset cannot be greater than the probability of its being a member of a set. Moreover, we believe that the same pragmatic processes that lead to apparent errors on conditional-reasoning tasks lead to reported errors on the Linda task.

1. The Wason Selection Task

The Wason selection task has been, over the last two decades, the most investigated deductive reasoning problem. In the standard version of the task subjects are presented four cards showing, e.g., A, D, 4, and 7, respectively, are informed that each card has a letter on one side and a number on the other side, and are given the rule *If a card has a vowel on one side, then it has an even number on the other side*. Subjects are then told that the rule may or may not be true and are required to select for inspection those cards, and only those cards, that can provide a test of whether the rule is true. Because only the cards showing A (a vowel) and 7 (not an even number) can lead to potentially falsifying evidence, these are the only cards that should be selected. Subjects rarely make the correct selections, instead tending to select the cards showing A and 4, or

sometimes just the card showing A (see Evans, 1982, for a review). Although early investigators interpreted the modal error pattern as reflecting a confirmation strategy, rather than a falsification strategy, Evans (1972; Evans & Lynch, 1973) has provided evidence that subjects' selections reflect a primitive matching bias, in which subjects merely select cards on the basis of a simple match between properties in the exemplar and those named in the rule.

Cheng *et al.* (1986) have argued that because some subjects fail to select the card showing the A, *modus ponens* is not an inference schema that is universally available. Consider, however, what is required to know that the card showing an A should be selected. First, one needs to suppose that the rule is true. Then, given that the letter A is a vowel, by *modus ponens* it follows that the other side of the card must show an even number. However, if the card were turned over to reveal an odd number, then, by *reductio*, the rule would be false (note that the supposition being falsified is the rule, not its antecedent). Clearly, *modus ponens* alone does not lead to the judgment that the card showing an A needs to be inspected. This selection requires a complex indirect reasoning strategy, and logical competence alone does not provide such a strategy.

When the selection task is presented with certain sorts of realistic content, both school-age children and adults perform at levels well above those that would be predicted by chance. For example, Johnson-Laird, Legrenzi, and Legrenzi (1972) reported that over 80% of their subjects made correct selections when presented with a postal rule, *If an envelope is sealed, then it must have at least a 50 lira stamp*, and four envelopes, one sealed, one unsealed, one with a 50 lira stamp, and one with a 30 lira stamp. Three theoretical explanations have been proposed to account for facilitative content effects. Griggs and Cox (1982) claimed that when a rule's content cues exemplars of counterexamples in long-term memory, subjects will make correct selections, e.g., *If a person is drinking beer, then that person must be at least 21 years old* is a familiar rule that is

stored with knowledge of its counterexemplars; when a rule's content is not stored in long term memory, subjects will attempt to reason by analogy to known information in long-term memory. However, no independent metric for memorial availability has been proposed, and reasonably good performance has been reported on several task versions with unfamiliar content (e.g., Cosmides, 1989).

Cheng and Holyoak (1985, 1989), Cheng *et al.* (1986), and Holland *et al.* (1986) proposed that content is facilitative when a pragmatic reasoning schema is activated. Pragmatic schemas are presumed to be inductively learned, and are content dependent. Two such schemas have been described, one for obligation and one for permission. For example, when one is presented a rule of the sort *If one is to take action A, then one must satisfy precondition P*, the permission schema is elicited, and the permission schema contains the knowledge that (a) taking action A requires precondition P, (b) when precondition P is not satisfied, action A is not permitted, and (c) when action A is not taken or when precondition P is satisfied, nothing is required. To date, these are the only pragmatic schemas that have been described. If the pragmatic-reasoning-schemas approach is to provide a general theory, then content-dependent schemas for all sorts of content that are understandable will have to be described — a rather large promissory note. Further, if the pragmatic-schema approach is correct, then it suggests a developmental scenario in which pragmatic schemas for different sorts of content enter into the reasoning repertory incrementally, schema by schema for each content area. Data on children's spontaneous use of *if* in conversation, however, do not support this scenario, and a variety of *if* statements seem to enter together (e.g., Bloom, Lahey, Hood, Lifter, & Feiss, 1980; Bowerman, 1986; Reilly, 1986).

Cosmides (1989) proposed that people have, as a result of their Darwinian evolutionary history, a set of special reasoning processes for social contracts. A social contract has the form *If a benefit is taken, then the cost must be paid*. Social contracts are special cases of

permission/obligation schemas, and Cheng and Holyoak (1989) reported several task versions that are permissions/obligations that are not social contracts, but that lead nonetheless to adequate performance. Further, Manktelow and Over (1990) question whether some versions that facilitate adequate performance have any discernible benefits or costs, e.g., what are the costs and benefits for a department store clerk in the rule *If any purchase exceeds $30, the receipt must have the signature of the department store manager* ?

Taken together, these authors tell the following story: on arbitrary-content versions of the task, subjects rely on non-logical heuristics; on certain realistic-content versions subjects do give the right answer, but they do so because they are able to apply content-dependent reasoning processes. They conclude that adequate reasoning is content-dependent, and that logic plays no significant role in human cognition.

To interpret these content effects on the selection task, albeit some interesting effects, as demonstrating that reasoning *typically* is governed by content-dependent schemas, or that there are sociobiological thought processes for social contracts, strikes us as wildly speculative. The relationship between data and theory in these arguments is far from direct. We do not think that the demands of the Wason selection task are typical of human reasoning situations. Rather, the task makes extra-ordinary strategic and processing demands. Hence, the generally poor performances reported on arbitrary-content versions of this task do not seem to us as convincing evidence against an important role for logical competence in human reasoning. What impresses us is not the failure of subjects to make correct selections on arbitrary-content versions of the task, but the success of certain sorts of content to provide sufficient pragmatic cues for correct solution. We do not see, however, why this should count as evidence for the proposition that human cognition is limited to content-dependent processes.

A final reason for our skepticism that performance on the selection task demonstrates content dependency comes from a recent investigation by Griggs (1989). Griggs argues that the selection task is difficult both because the materials are arbitrary and unfamiliar, and because the rule does not block the invited inference of *if not-p then not-q*. Griggs constructed a version of the task that refers to two decks of ordinary playing cards, one with red backs and one with blue. Subjects were told that four cards had been selected from the decks according to the rule that *If a card has a red back, then it must have at least a six*. On this task version 80% of subjects made the correct selections. We do not see how any of the content-dependent theories can account for the facilitative effect of Griggs's version.

2. Errors by Children in Conditional Reasoning

Poor performances on arbitrary-content versions of the Wason selection task hardly are surprising, given its complexity; however, several conditional-reasoning problems that are far simpler often lead to erroneous judgments by children, and occasionally by adults. The most common procedure for assessing reasoning with simple conditionals requires subjects to evaluate conditional syllogisms. There are four such problem forms, each having a proposition of the form *If p then q* as a major premise, and either *p*, *not-p*, *q*, or *not-q* as a minor premise, respectively.

The syllogism form with *p* as a minor premise is, of course, *modus ponens*, and children as young as 6 years old have no difficulty with it (see Braine & Rumain, 1983, and O'Brien, 1987, for reviews). Byrne (1989) has argued, however, that when one presents two conditional premises, e.g., *If she has a paper to write, she'll work late in the library* and *If the library stays open, she'll work late in the library*, even adult subjects will fail to make a *modus ponens* inference from *She has a paper to write*. As Politzer and Braine (1991) note, however, the second conditional premise leads one to doubt that the argument is based on true premises, i.e., they

doubt the truth of *If she has a paper to write, she'll work late in the library*. Thus, although modus ponens is a valid argument, this argument is not sound, i.e., proceeding from true premises.

The two syllogisms with *not-p* and *q*, respectively, as minor premises are not valid argument forms, but many children, and some adults, assert as conclusions, *not-q* and *p*, respectively. Several investigators have interpreted these errors by children as stemming from a lack of competence, with children limited to understanding conditionals as biconditionals (e.g., Knifong, 1974; Matalon, 1962). Rumain, Connell, and Braine (1983) provided evidence that the acceptance of these fallacies reflects not a lack of competence, but rather the acceptance of the invited inference from *If p then q* to *If not-p then not-q*. When the major premise is amended to *If p then q, but if not-p then maybe q or maybe not-q*, even children no longer accept the fallacies. If children accepted the fallacies because they lack the logical competence to encode a conditional, the Rumain *et al.* manipulation would not have had this facilitative effect.

The syllogism form with *not-q* as a minor premise is, of course, modus tollens. Children usually give the correct response on these problems, i.e., that *p* is false. Adults, however, often respond "can't tell." The correct responses of children appear to result from the same invited inference that leads to the two fallacies just discussed, and the frequency of such correct responses is reduced when children are presented the extended conditional premise, *... and if not-p then maybe q or maybe not-q*. We are not surprised that subjects find this problem difficult. Unless people have *modus tollens* in their basic reasoning repertory, and the Braine *et al.* (1984) and Lea *et al.* (1990) model does not include it, adequate understanding requires a *reductio* argument with the use of the indirect reasoning routine.

Another set of investigations has presented conditional sentences and asked children to judge their truth or falsity given exemplars of the forms *p and q*, *not-p and q*, *p and not-q*, and *not-p and not-q*, respectively (e.g., Paris, 1973; Staudenmeyer & Bourne, 1977; Taplin, Staudenmeyer, &

Tadonio, 1974). These authors have reported that young school-age children often respond as though *if* were a conjunction, i.e., as though *if* meant *and*. That children interpret *if* as *and*, however, is unlikely; this would make the premises of modus tollens contradictory, and at no age do subjects indicate that they think this. The responses are interpretable from the perspective of the competence model. When faced with a conditional to be evaluated, subjects should apply the schema for conditional proof, beginning by supposing the antecedent *p* and trying to assess the consequent *q*. For exemplars in which *p* is true subjects should have no difficulty, responding "true" when *q* is true, and "false" when *q* is false, and this is exactly how subjects at all ages respond. For exemplars in which *p* is false, however, the schema for conditional proof is blocked, and subjects would be expected to respond "can't tell" when such a response option is available. This is the response that Johnson-Laird and Tagart (1969) found with adult subjects when the option was provided. When the indeterminate response option is not available, subjects are faced with a quandary — the conditional and the exemplar seem to be unrelated, and the Gricean cooperative principle violated. Because either a "true" or a "false" response is required, the "false" is given because it seems less unreasonable. Thus, the modal conjunction-like response pattern does not reflect a conjunction interpretation; it reflects appropriate logical processing when *p* is true, and an attempt to make a pragmatically reasonable response when *p* is false.

In summary, both children and adults exhibit the logically appropriate responses on problems for which the competence model predicts they should. When faced with problems that are beyond their competence, or that violate pragmatic expectations, they provide responses that seem pragmatically acceptable. We do not see that the critics have established their case that children are lacking a basic logic competence that allows for an appreciation of conditionals.

3. The Linda Problem

Tversky and Kahneman (1982, 1983) claimed that when people make probability judgments they do not consider normative rules for probability, but instead rely on non-logical heuristics, such as representativeness and availability. Consider the Linda problem, in which subjects are given a description of Linda:

(3) Linda is thirty-one years old, single, outspoken and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice, and also participated in anti-nuclear demonstrations.

Subjects are asked to rank order the probabilities of several possibilities, including these:

(4) Linda is a bank teller.

(5) Linda is active in the feminist movement.

(6) Linda is a bank teller and is active in the feminist movement.

Note that (6) is the conjunction of (4) and (5), and thus should not be judged as more probable than either of its conjuncts. Tversky and Kahneman reported, however, that most of their college-age subjects violated the normative conjunction rule, and rated (6) as more probable than (4). These erroneous judgments were interpreted by Tversky and Kahneman as evidence for the representativeness heuristic — (6) contains one feature that matches the description in (3), whereas (4) has no matching features.

Politzer and Noveck (1991) have questioned the extent to which these responses impeach the ability of subjects to appreciate the appropriate set relations. Two task features, they argue, make the problem misleading. First, the problem requires a comparison between a set and its proper subset — a peculiarity shared with the class-inclusion problems of Inhelder and Piaget (1964), in which children were asked whether there are more primulas or flowers; five-to-7 year olds respond that there are more primulas. McGarrigle, Grieve, and Hughes (1978) and Shipley

(1979) provided evidence that the error comes from interpreting *flowers* to mean *flowers that are not primulas*.

The second peculiar task feature concerns the description in (3): it plays absolutely no role in making the normatively correct judgment. Gricean principles, however, would lead subjects to expect that the information in the description would be of some relevance to task solution. Taken together, the two peculiar task features invite subjects to interpret (4) to mean:

(4') Linda is a bank teller and is not active in the feminist movement.

With this interpretation, (6) reasonably seems more probable than (4'), as subjects judge it to be, because (6) seems consistent with the description in (3), whereas (4') seems inconsistent with (3).

Politzer and Noveck presented a version of the task that provides this description of Daniel:

(7) In high school, Daniel was always good at Math and Science. He likes human contact, he has a strong sense for helping others, and he is very determined.

The possibilities to be rank ordered according to their probability included:

(8) Daniel entered Medical school.

(9) Daniel graduated from Medical school.

The Daniel problem differs from the Linda problem in that (a) the description in (7) is equally relevant to both (8) and (9), and (b) the set/subset relationship is clarified because (8) is a necessary condition for (9). Thus, the Daniel version reduces the sources of pragmatic difficulty on the Linda problem. On the basis of representativeness, there appears to be no reason to view either possibility as more probable than the other, and representativeness predicts that 50% of subjects will make a conjunction-rule violation. Politzer and Noveck reported, however, that few subjects violate the conjunction rule on this version.

In sum, poor performance on the Linda problem is weak evidence for Tversky and Kahneman's claim that people rely on representativeness rather than mathematical intuition when making probability judgments. As the Daniel problem shows, most people are able to appreciate the conjunction rule when the pragmatic peculiarities of the problem are minimal.

III. Logic and Pragmatics in Text Comprehension

Text and discourse comprehension research provides a fertile ground on which to investigate how logic and pragmatics work together in an inference-making situation that is common to almost everyone, i.e., reading. When understanding most texts, a reader must elaborate on the information stated explicitly in the text by making a variety of inferences. Usually a text will require the reader to connect elliptical statements, and people's competence in doing so allows communication to be efficient; the writer, or speaker, need only provide an outline that readers, or listeners, fill in with inferences. A variety of inferences have been investigated in the text-processing literature, including pragmatic inferences such as case inferences (e.g., Corbett & Dosher, 1978), causal inferences (e.g., Keenan, Baillet, & Brown, 1984), trait inferences (e.g., Newman & Uleman, 1989), goal-related inferences (e.g., Abbott & Black, 1986), thematic inferences (e.g., Kieras, 1985), inferences from story grammars (e.g., Mandler and Goodman, 1982), and inferences from scripts (e.g., Bower, Black, & Turner, 1979). Common among these pragmatic inferences are processes that combine information presented explicitly by the text with information in the reader's long-term memory. Structures such as scripts and story grammars consist of clusters of knowledge in memory about prototypical conditions, behaviors, or situations. When a writer chooses to omit details from the text, a reader can rely on the schematic structures to furnish that information when it is necessary (Seifert, Robertson, & Black, 1985).

Because these pragmatic inferences are probabilistic rather than deterministic, however, readers can be seduced into inferring material relevant to the typical instance but not to the particular one, thus leading to spurious inferences and conclusions. Although reasoning research has focused on how such non-logical inferences can account for acceptance of invalid arguments, the literature concerning text comprehension has concerned itself mainly with the apparent miracle of successful comprehension. This work in text comprehension is consistent with work by Grice (1975) and others concerning discourse assumptions that permit speakers and listeners to cooperate in their communication, thus allowing for efficient and coherent discourse; many discourse "mistakes" can be accounted for by the failure to apply these principles appropriately.

Consider the following brief text as an illustration of how a variety of different sorts of inferences, both pragmatic and logical, can operate together:

(10) Jerry was trying to decide what to wear to meet his fiancee's parents.

(11) "I'd like to wear either my striped or my checkered shirt," he thought.

(12) "If I wear my striped shirt, I'll have to wear my blue pants since they match the shirt," he thought, "but I'm not sure where my blue pants are."

(13) He looked in his closet for his checkered shirt and saw that it was wrinkled, so he decided he could not wear that.

(14) "So I'd better find my blue pants," he thought.

Note that (10) presents the *theme* of the passage. The knowledge structure relating to dressing oneself, e.g., the dressing *script*, would be elicited by this topic sentence, permitting the author to focus on Jerry's decision about what to wear, rather than on an exhaustive dissection of the process of dressing. Knowledge about social protocol relating to meeting a fiancee's parents might be accessed, thus allowing a reader to infer that Jerry's goal

is to make a good impression, that is the *plan* to achieve the goal includes his appearance, and that the *instruments* involved in his plan include the clothes he decides to wear.

However, readers must also make inferences that are not pragmatic in order to comprehend the story in (10)-(14). For example, the anaphoric inference that "he" in (11) refers to "Jerry" in (10) must be made if a reader is to appreciate that the person who is deciding about shirts is the same person who is about to meet his fiancee's parents; this reference needs to be maintained in each of the remaining sentences. Also required for the comprehension of the story are propositional-logic inferences. Unless the disjunction *or* in (11), the conditional *if* in (12), and the negation *not* in (13) are understood, and the appropriate inferences drawn from them, the story would be difficult, if not impossible, to comprehend. In an experiment by Lea *et al.* (1990), subjects read such stories and were given two tasks. A *validity task* asked them whether the final sentence makes sense in the context of the story. For example, for the story above, subjects saw either (14) or the following sentence:

(15) "So I don't have to find my blue pants," he thought.

Note that unless the reader made the logical inferences predicted by the model while reading the story, it would be difficult, if not impossible, to determine whether sentence (14) or (15) makes sense in the context of the story. Lea *et al.* found that subjects correctly accepted the appropriate final sentences, e.g., (14), and correctly rejected logically unsound sentences, e.g., (15), 94% of the time. A second task, the *recognition task*, required subjects to indicate whether a given piece of information was presented explicitly by the text, or whether it had to be inferred. Subjects were given three types of information for each story: (a) a paraphrase of information presented explicitly in the text, (b) an inference that follows from the story propositions by application of the schemas of the model, and (c) an inference that is valid in standard logic but would not have been drawn by

the model. For the story in (10) - (14) the recognition items were the following:

(16) Paraphrase: Jerry decided not to wear his checkered shirt.

(17) Model: Jerry eventually decided to wear his striped shirt.

(18) Non-model Valid: If Jerry did not wear his blue pants, he would have worn his checkered shirt.

Subjects often (69%) falsely recognized the model inferences as having been presented in the text, although they rarely did so with the non-model valid inferences (17%). Such recognition false alarms, along with recall intrusions, are the hallmark of text-comprehension research that has established pragmatic inferences as being part of a reader's memorial representation of a text, which appears to be a composite trace of information presented in the text together with information from the reader's preexperimental knowledge (Walker & Yekovich, 1984). When a reader consults this trace, it can be difficult to determine exactly what was inferred and what was presented. Several prominent studies have measured recognition and recall intrusions to investigate such sorts of inferences as surface-structure syntactic (e.g., Bransford & Franks, 1971), spatial (e.g., Bransford, Barklay, & Franks, 1972), inferences from scripts (e.g., Bower, Black & Turner, 1979; Walker & Yekovich, 1984), and goal, plan, action, and state inferences (e.g., Seifert *et al.*, 1985). In the case of the propositional-logic inferences investigated by Lea *et al.*, the information produced by the model inference schemas is added in the reader's memory trace to the propositions presented in the text; no pre-experimental knowledge is required to execute model inferences, as is demonstrated by the box and blackboard problems such as those described earlier. Further, these inferences were made in the text-processing situation so effortlessly and spontaneously that subjects generally did not realize that they were making inferences at all.

The result of 94% correct on the validity task, when considered together with similar results on comparable blackboard problems devoid of

pragmatic content (e.g., Braine *et al.*, 1984, 1990; Lea *et al.*, 1990; Fisch, 1990), suggests that pragmatic processes and logical processes can work concurrently without a loss of logical or pragmatic reasoning performance. The stories from Lea *et al.*, such as the story in (10) - (14), elicit pragmatic as well as logical inferences, though only the logical inferences were investigated experimentally. We see no reason why pragmatic and logical inferences not only coexist, but also feed directly into each other. For example, consider the following substitution for (13):

(13') He looked in his closet for his checkered shirt and saw that it was torn to shreds.

Presumably, Jerry's goal of making a good impression on his fiancee's parents with a positive appearance excludes wearing a torn shirt, and therefore excludes the checkered shirt. This inference is purely pragmatic, and yet would feed into the disjunct "striped or checkered" just as well as the given information in (13) that Jerry "decided he could not wear that."

To summarize, our claim is that people's ability to perform important and distinctly human activities, such as discourse processing, includes a competence in both logical and pragmatic reasoning, and that text comprehension research presents a promising case study in the ways in which pragmatic and logical inferences perform complementary rather than competitive roles in the acquisition and processing of information. Further, the logical competence captured by the model is not limited to peculiar laboratory tasks, such as those discussed earlier, but that it plays a useful role in such ordinary activities as reading a text. The variety of pragmatic text inferences mentioned in this section account for a richness and breadth in comprehension that logical competence, by itself, does not address and for which it cannot account. Thus, the human reasoning repertory apparently includes a family of inferential processes, most of which are necessary, but none sufficient, for the comprehension of the variety of texts available in a typical library.

IV. Summary

On standard laboratory reasoning tasks, subjects do not always respond in accord with the normative output of standard logic or probability theory. We do not think that this necessarily counts as evidence against a significant role in human cognition for a logical and mathematical competence. On those laboratory tasks for which the Braine *et al.* (1984) and Lea *et al.* (1990) competence model predicts adequate performance, neither children nor adults have any apparent difficulty. On problems that violate normally operating pragmatic expectations, or that require the complex strategies of the indirect reasoning routine, however, subjects often exhibit erroneous judgments. We think that this counts as evidence for our three-part approach: (a) a set of inference schemas accounts for the predicted correct judgments, (b) a reasoning program implements the schemas, and (c) a set of independently motivated pragmatic priciples interprets stimuli and suggests the goals of the experimenter to the subject.

The evidence supports an account of human cognition that features both logical and pragmatic processes that work independently (e.g., on the box and blackboard problems), jointly with positive results (e.g., in text comprehension), or jointly with negative results (e.g., on problems where subjects accept the classical conditional-reasoning fallacies). In particular, we do not see that any case has been made for the proposition that reasoning typically is content dependent — proponents of that position would need to explain why a variety of content-dependent rules all are expressed with the same logic particle, e.g., *if* for conditionals, and why a wide variety of contents are found with the particle in ordinary discourse, including many that do not fall in the realm of the content-dependent rules.

Finally, we think that the poor performances on complex tasks show that some researchers are very clever at constructing tasks that trick people. Although it is of interest to discover to what tricks people are prey

and how they respond when tricked, we should not be misled into believing that this reveals how people proceed in ordinary thought.

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