INCREASING INFORMATIVENESS AND REDUCING INDETERMINACY: AN ADAPTIVE CONSTRAINT IN CHILD COGNITION

Vladimir M. Sloutsky
Center for Cognitive Science
The Ohio State University

Bradley J. Morris
Department of Human Development and Center for Cognitive Science
The Ohio State University
and
Department of Psychology
Carnegie Mellon University

Aaron W. Rader
Department of Psychology and Center for Cognitive Science
The Ohio State University

Running Head: Informativeness bias

Address correspondence to:
Vladimir M. Sloutsky
Center for Cognitive Science
21 Page Hall
1810 College Road
The Ohio State University
Columbus, OH 43210
Phone: (614) 688-5855
Fax: (614) 292-0321
Email: Sloutsky.1@osu.edu

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ABSTRACT

Many studies of children's reasoning and problem-solving indicate that children do not represent all possibilities compatible with a problem and instead truncate a problem's representation. The paper explores this phenomenon by considering the information value of a verbal proposition as a predictor of whether the proposition is represented veridically or in a simplified manner. The prediction was tested in three experiments conducted with young children. The results of the experiments demonstrated that young children have a bias against less-informative, empirically indeterminate propositions and that they systematically ignore parts of these propositions, thus converting less informative propositions into more informative ones. This phenomenon sheds light on how children represent problems. The results of the experiments are discussed in relation to theories of problems solving and scientific and logical reasoning.

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People have to function in a world that is fundamentally uncertain -- both perceptual and cognitive cues are compatible with multiple possibilities, and often there is not enough information to decide among these possibilities. For example, visual scenes typically contain partially occluded objects, and it is not known with certainty what these occluded parts are or might be. Language represents an even larger challenge by affording explicitly indeterminate propositions, e.g., "I will stop by or I will see you tomorrow."

There are several constraints that seem to limit indeterminacy, helping people navigate in this world. First, they may have some a priori assumptions and biases. For example, even infants may expect objects to behave in a particular manner, and not in other possible manners (Spelke, Phillips, & Woodward, 1995; Spelke, Breinlinger, Macomber, & Jacobson, 1992), while toddlers may expect words to refer to the whole objects, but not to parts of these objects (Markman, 1990). Second, there are statistical constraints, such as base rates, limiting the range of considered possibilities. For example, when presented with the word MOD----, and asked to insert missing letters, people would be more likely to answer with the more frequent *MODESTY* than with the less frequent *MODICUM*. Similarly, a partially occluded dog is more likely to be a dog than part-dog and part-bird. As a result of these assumptions and constraints, people often construct simplified mental representations (or models of the world) that deviate from what is afforded by available information.

Simplification tendencies are most obvious in higher-order cognition, such as reasoning problem solving, and decision-making of both children and adults. Research findings indicate that participants tend to deviate from prescriptive standards and instead use heuristics that afford the simplification of problems (Acredolo & Horobin, 1987; Bindra, Clarke, & Shultz, 1980; Fay & Klahr, 1996; Horobin & Acredolo, 1989; Klahr, Fay, & Dunbar, 1993; Scholnick & Wing, 1988; see also Evans & Over, 1996; Johnson-Laird & Byrne, 1991; Simon, 1969; Tversky & Kahneman, 1982 for extensive reviews and discussions). These simplification tendencies are even more conspicuous in children who often tend to construe extremely simplified mental representations, eliminating most of these possibilities.

In this article we attempt to examine some of these simplification tendencies in young children's reasoning. We argue that these simplification tendencies may stem from young children's assumptions about the correspondence between verbal descriptions and states of the world. These assumptions, while leading to systematic errors, may help children to handle indeterminacy. To elaborate upon this proposal, we deem it necessary to quantify indeterminacy. In so doing, we analyze indeterminacy using the concepts of semantic information value (Bar-Hillel, 1964) and information gain.

Information Value and Indeterminacy

Consider a set of entities in the world $\{O_1, O_2, O_3, ..., O_n\}$. These entities could be individual objects (e.g., a dog), classes of similar objects (small dogs), or states of the world ("The dog fights with a cat."). Consider also a set of information cues $\{C_1, C_2, C_3, ..., C_n\}$ corresponding to the first set, and communicating information about it. These could be perceptual cues, objects, visual arrangements, words, or propositions. The value of an information cue is inextricably related to alternative possibilities eliminating by this cue: the more possibilities it eliminates, the larger its information value (Bar-Hillel, 1964). For example, consider a spatial arrangement of three balls X, Y, and Z. The description "Y is in the arrangement" is compatible with six possible arrangements, the description "Y is to the left of Z" is compatible with three possible arrangements, while the description "Y is right of X and left of Z" is compatible with a single possible arrangement. Thus the first description is less informative than the second, which in turn is less informative than the third.

Let us present these intuitions in a more formal way. Consider a simple task. There are 20 blocks in a bag. Out of these 20 blocks, 5 are yellow stars, 5 are yellow triangles, 5 are blue stars, and 5 are blue triangles. Suppose that Person A draws an object at random from the bag and describes it to Person B, whereas Person B has to identify the object. If there is no description provided, then the probability of identifying the object equals to its base rate. In our case, all objects are equally probable; hence the probability equals to .25. However, if Person A provides a description of the object, the probability of identifying the object may increase. We define this increase in the probability as information gain (I_g) due to description (see Oaksford & Chater, 1994; Oaksford, Chater, Grainger, & Larkin, 1997, for other treatments of information gain). According to the definition, information gain is equal to the difference between the probability of identifying the object given the description and the probability of identifying the object relying on base rates alone. Information gain is presented formally in Equation 1.

$$I_g = P(ID|D) - P(ID) \qquad (1)$$

where $P(ID|D)$ is a probability of identifying the object given the description and $P(ID)$ is the base rate of the object, or the probability of identifying the object by chance alone.

Suppose that the object drawn from the bag is a yellow star. What is the probability of identifying the object given each of the following verbal descriptions: (1) *The object drawn is yellow*, (2) *The object drawn is a star*, (3) *The object drawn is yellow or it is a star*, (4) *The object drawn is yellow and it is a star*? These probabilities could be computed using Bayes' Theorem:

$$P(ID\,|\,D) = P(ID)\frac{P(D\,|\,ID)}{P(D)}$$

(2)

That is, the probability of identifying the object given the description is proportional to the base rates, the probability of the description (i.e., the probability that the description is true) assuming the object has been identified, and the probability of the description. Because $P(D|ID)$, the probability that the description is true assuming that the object has been identified (for example, as a yellow star) equals to 1, we can simplify Equation 2. This simplification is presented in Equation 3.

$$P(ID\,|\,D) = \frac{P(ID)}{P(D)}$$

(3)

Therefore, I_g for a description could be calculated using Equation 4:

$$I_g = \frac{P(ID)}{P(D)} - P(ID) = P(ID)(\frac{1}{P(D)} - 1)$$

(4)

Thus, information gain is proportional to the base rates and the probability of the description. When base rates are known, such as in the task above, $P(D)$ equals the proportion of objects compatible with the description. For example, for the description *The object drawn is yellow*, $P(D) = .5$, whereas for the description *The object drawn is yellow and it is a star*, $P(D) = .25$. Information gain for each of the four descriptions is presented in Figure 1. As shown in the figure, the description that affords complete determinacy (*The object drawn is yellow and it is a* *star*) yields the largest information gain.

However, in the majority of real life tasks, both base rates and proportions of possibilities compatible with descriptions are unknown. In this case, $P(D)$ could be approximated by the logical probability of the description being true (Bar-Hillel, 1964), and information gain could be approximated by the inverse of $P(D)$. According to probability theory and the semantic information theory (Bar-Hillel, 1964) when $P(A) \neq 0$, $P(B) \neq 0$, and $A \neq B$, $P(A \text{ or } B) > P(A) > P(A \text{ and } B)$. Therefore, descriptions of the form *A and B* yield larger information gains than descriptions of the form *A*, *B*, and *A or B*. In short, a cue C_i (e.g. a verbal description) yields the largest information gain when C_i identifies uniquely the state of affairs (e.g., the object that was drawn). In this case, the, problem of inference from C_i to some entity O_k (e.g., identifying the object given the verbal description) is determinate; otherwise the problem is indeterminate, and C_i is less informative.

If children consider verbal propositions in a manner similar to perceptual and spatial arrangements (i.e., as descriptions of states of affairs), it seems plausible that they would assume that each description could be uniquely mapped onto a particular state of affairs. In this case, each description would be completely determinate, thus yielding the largest information gain. Of course, we do not expect people to compute information gain; we rather suggest that information cues yielding larger information gain might be their default expectation. In other words, children might expect words, statements, and verbal descriptions to uniquely identify states of affairs, eliminating all but one possibility.

There are many findings indicating that less informative statements lead to larger difficulties, and that children tend to simplify indeterminate problems by confusing them with determinate ones, but not vice versa. Supporting evidence exists in learning, problem solving, verbal and scientific reasoning, and decision making.

Both human and animal species tend to avoid learning less informative, indeterminate cues (see Estes, 1988, 1994; Gallistel, 1990, for reviews). For example, young children were found to experience difficulties in the acquisition of homonyms (i.e., a single word corresponding to different objects); however, these difficulties could be overridden by presenting children with several examples of homonyms (Backscheider & Gelman, 1995). Studies of classification learning demonstrate that the difficulty of learning a classification increases when the same identifying stimulus is assigned to different classes of objects or to highly dissimilar objects (Gibson, 1940; Shepard, Hovland, & Jenkins, 1961).

In problem solving and rule discovery tasks, when evidence (C_i) corresponds to a number of possible states of the world, or hypotheses (O_j, O_k, O_n), participants tend to overlook indeterminacy of the problem, and selectively attend to evidence matching their hypotheses (Acredolo & Horobin, 1987; Bindra, et al., 1980; Byrnes & Overton, 1986; Fay & Klahr, 1996; Horobin & Acredolo, 1989; Klahr, et al., 1993; Kuhn, Garcia-Mila, Zohar, & Andersen, 1996; Mynatt, Doherty, & Tweney, 1977; Piéraut-LeBonniec, 1980; but see Sodian, Zaitchik, & Carey, 1991 for diverging evidence; see also Klayman & Ha, 1987 for a discussion). For example, in the box task (Fay & Klahr, 1996; Piéraut-LeBonniec, 1980) a child is presented with two boxes (O_1 and O_2), with one box containing stars and triangles, and another containing triangles and squares. Then the child is shown a shape (C_i) and asked to determine from which box the shape comes. The problem is determinate for stars and squares (each of them corresponded to a single O), but it is indeterminate for triangles (since they correspond to both O_1 and O_2). Young children had no difficulties solving the problem when it was determinate, whereas they had much more difficulty solving the problem (i.e., answering “can’t tell”) when it was indeterminate.

Furthermore, the pattern of errors indicated that children overlooked indeterminacy of the latter problem, acting as if there was a unique solution.

Children (and adults) were also found to experience larger difficulties interpreting indeterminate propositions such as "if … then" conditionals that are compatible with three states of the world than interpreting propositions compatible with just one state of the world, such as conjunctions (Evans & Over, 1996; Johnson-Laird, Byrne, & Schaeken, 1992; Klauer & Oberauer, 1995; Sloutsky & Goldvarg, 1999; Staudenmayer & Bourne, 1977; Taplin, Staudenmayer, & Taddonio, 1974).

In set formation experiments, children exhibit difficulties forming disjunctive sets (Greer, 1978; Neimark & Slotnick, 1970; Paris, 1973; Suppes & Feldman, 1971). Children often ignore part of a disjunction (e.g., they bring only yellow things when asked to bring yellow things or green things), with the first mentioned disjunct more likely to be attended to (Braine & Rumain, 1981; Suppes & Feldman, 1971). Children also often interpret disjunctive sets (e.g., *round or blue*) as conjunctive ones (*round and blue*) (Suppes & Feldman, 1971).

Since indeterminate problems are less informative than determinate problems (because indeterminate problems do not allow one to reach a unique solution), they are likely to be construed veridically. Therefore, there seems to be a general relationship between problem determinacy, informativeness, and the probability of error. Less informative problems are more likely to elicit erroneous answers than more informative problems, and they are more likely to be confused with more informative problems than vice versa.

If this contention is true, then, it should have an important implication for another class of problems: those that have no information value. These are verification of logically determinate statements, namely tautologies and contradictions, the truth status of which can be determined *a* *priori* from their logical form. For example, the statement “Bill is a frog or Bill is not a frog" is an *a priori* true tautology, whereas the statement “The Earth revolves around the Sun and the Earth does not revolve around the Sun” is an *a priori* false contradiction. It follows from Equation 4 that information gain due to tautology is 0 (because the logical probability $P(D)$ of the tautology equals to 1), whereas information gain due to contradiction is undefined (because the logical probability $P(D)$ of the contradiction equals to 0). Therefore, if our contention is true, young children should exhibit difficulties with logically determinate problems similar to those they experience with indeterminate problems. Of course, it is entirely possible that children would balk at a contradiction, at a tautology, or at both; however, in prior research this has not taken place. In fact, there is evidence that young children systematically confuse both types of logically determinate problems with empirical ones, attempting to solve the former as if they were the latter (Morris & Sloutsky, in press; Osherson & Markman, 1975), whereas we were unable to locate evidence indicating that children confuse empirical problems with logically-determinate ones.

We suggest that these tendencies to mistake logically determinate problems for empirical ones, and empirically indeterminate problems for empirically determinate ones, stem from a systematic bias against low information value — children tend to construe a very simplified problem representation, one compatible with a single possibility. We do not think that children in any way compute possible information gains. We rather suggest that they assume the complete determinacy of verbal descriptions. Thus, maximal information gain is not a product of computation, but rather a consequence of the mentioned assumption. Such an assumption biases the child against considering multiple possibilities, thus allowing “fast and frugal” analysis of incoming information. While this bias hinders some aspects of higher-order cognition (e.g., scientific or mathematical reasoning), it may not have adverse affects on practical reasoning and solution of everyday problems (see also Gigerenzer & Goldstein, 1996).

If our general hypothesis is correct, and children expect verbal descriptions to yield maximal information gains, uniquely identifying states of affairs, then when presented with verbal descriptions of states of affairs, young children should not attempt to simplify the most informative propositions and should attempt to simplify less informative ones. If this prediction is supported, we deem it necessary to provide descriptive accounts of heuristics that young children may use when simplifying less informative problems.

Our prediction was tested in three experiments. In the first two experiments, preschoolers were presented with predictions about the outcomes of a game with two possible outcomes, whereas in the third experiment the game had four possible outcomes. Some predictions were empirical statements, such as affirmations (*A*), negations (*not-A*), conjunctions (*A and B*), and disjunctions (*A or B*), while others were logically-determinate tautologies (*A or not-A*) and contradictions (*A and not-A*). Participants were asked to evaluate the truth of each prediction and whether or not the prediction should be tested. After each game was played, participants again had to evaluate the truth status of the prediction. These experiments allowed us to test the hypotheses and to provide descriptive accounts of children's treatment of propositions varying in their information gains.

EXPERIMENT 1

The first goal of this experiment was to test the prediction that children tend to simplify logically-determinate problems (i.e., tautologies and contradictions) by representing them as if they were empirical problems. Another goal was to describe simplification heuristics used by young children.

Method

Participants

Participants were 27 four- to five-year old children (*Mean age* = 4.6 years, *SD* = 0.75 year; 15 girls and 12 boys) enrolled in a Columbus area childcare center. Children representing four different classrooms within the childcare center were selected on the basis of returning a parental consent form.

Materials

The experimental tasks consisted of a series of predictions by an imaginary character, ZZ, as to the outcome of a ball dropped in the Tautology Machine. The Tautology Machine is a 21" x 24" board (see Figure 2 below) with a chute at the top in which a ball dropped will fall through several obstacles; the obstacles direct the ball to one of two terminating points marked by red and green colors (in this experiment labeled "A" and "B").

The imaginary character ZZ made four predictions regarding the outcomes of the game. There was one prediction for each of these syntactic forms: tautologies, contradictions, affirmations, and negations. Predictions (presented in the order below) were as follows:

Tautology: The ball will land on A or not A.

Contradiction: The ball will land on A and not A.

Affirmation: The ball will land on A.

Negation: The ball will land on not A.

Procedure

In this experiment there was one within-subject factor, the syntactic form of the prediction. The experiment was conducted in a single 10-15 minute session that included two phases: a warm-up/instruction phase and the experimental phase. Each participant was tested individually in a quiet room. The participants were videotaped in order to ensure accurate coding of responses. In the warm-up phase, each child was read a set of instructions that explained the purpose of the game as evaluating the predictions of ZZ. Children were given three statements by ZZ that they were to evaluate to familiarize themselves with the experiment and to determine their ability to render each type of judgment. All 27 children could distinguish between statements that were explicitly true (e.g., "It is raining outside" on a rainy day) and explicitly false (e.g., "It is summer now," when in fact it was winter or fall); therefore, none of the children were dismissed from the experiment.

All instructions and predictions were read to each participant and repeated if requested. Participants were asked three questions about each prediction: a) an initial evaluation of truth status of the prediction (*a priori* evaluation), b) whether the *a priori* evaluations should be tested empirically (request for empirical verification), and c) a post test (*a posteriori*) evaluation. Each question was asked on the basis of the participant's response to the prior question. In the *a priori* evaluation of each prediction, participants were asked to evaluate the *a priori* truth status of the prediction as "Not True", "True", or "Can't Tell." After making the initial evaluation, the participants were asked whether or not an empirical verification was needed: "Do we need to drop the ball to check if ZZ was right?" When empirical verification was requested, the ball was actually dropped through the machine. In this case, an *a posteriori* evaluation was requested from the participant to assess the impact of the given state of the world on the initial prediction. In *a posteriori* questions, the participants were asked to again evaluate the initial predictions as "Right", "Wrong" or "Can't Tell" after establishing the ball's landing.

Results and Discussion

The analysis of *a priori* evaluations indicates that children did not distinguish between tautologies, contradictions, and contingent statements (see Table 1). It has been suggested that children younger than six years of age might be biased against providing “Can’t Tell” responses to indeterminate problems (e.g., Braine & Rumain, 1983; Pieraut-Le Bonniec, 1980). However, as the data in Table 1 indicate, many participants in this experiment did produce this response. It is also instructive to note, however, that frequencies of this response did not differ according to the logical form of the prediction, being roughly as likely to occur with tautologies and contradictions as with contingent statements.

For all four propositions, all participants requested to drop the ball in order to test the truth status of the proposition, something that should be expected from children who are interested to see the device working. After the ball was actually dropped, responses presented in Table 1 changed dramatically. These new responses are presented in Table 2.

Data in the table indicate that, for participants, the truth status of the prediction is a function of the actual outcome of the ball’s landing rather than the form of the prediction. To determine associations between the evaluation of the proposition as true or false and the ball's landing, each row in the table was subjected to 2 x 2 chi-square analyses. For all four predictions, associations (ϕs) between the ball's landing and the truth status children attributed to the propositions appeared to be very high. These results indicated that children do not distinguish among propositions that are always true (i.e., tautologies), always false (i.e., contradictions), and sometimes true and sometimes false (affirmations and negations), treating the two former predictions in the same manner as the latter two. In particular, children determined the truth status of a tautologous or a contradictory prediction by the consistency of the ball’s landing in accordance with the first or affirmatory clause of the prediction. These findings suggest that children may have ignored a part of tautology or a contradiction, converting these statements into more informative affirmative statements.

However, it remained unclear whether participants ignored the second clause or a negation clause — in the tautology and contradiction predictions, the second clause was always a negation. Therefore, we deemed it necessary in the following experiment to vary the type of the first proposition in tautologies and contradictions (i.e., sometimes affirmation first, sometimes negation first). If children's attributions of the truth status of predictions are determined by the consistency of the first part of a tautology or a contradiction with actual outcomes, then we could conclude that children simply cut the second half of a compound proposition. In this case, the prediction "The ball will land on A or/and will not land on A" should be evaluated as true if the ball lands on A, and false otherwise, whereas the prediction "The ball will not land on A or/and it will land on A" should be evaluated as true if the ball lands on B, and false otherwise. On the other hand, if children's attributions are determined by the consistency of the outcomes with an affirmation, then children should tend to convert tautologies and contradictions into affirmations by ignoring the negation component of the compound statements regardless of whether it is stated first or second. In this case, both "The ball will land on A or/and will not land on A" and "The ball will not land on A or/and it will land on A" will be evaluated as true if the ball lands on A, and false otherwise. We conducted the second experiment to test these possibilities.

EXPERIMENT 2

Experiment 2 was an attempt to replicate and clarify some of the results of Experiment 1. Two major changes were made in the procedure of Experiment 1. First, to determine whether participants cut the second half of non-informative statements, or selectively pay attention only to affirmative information contained in a tautology or a contradiction, we varied the type of the first proposition in tautologies and contradictions. In addition, to eliminate possible effects of knowledge of alphabetic information, the names of the terminal positions on the tautology machine were changed to colors (Red and Green).

Method

Participants

The participants were 34 four- and five- year-old children (*Mean age* = 4.9 years, *SD* = 0.4 year; 16 girls and 18 boys) recruited in two childcare centers in Columbus, Ohio. These participants were selected on the basis of returning a parental consent form.

Materials

The tasks were similar to those in Experiment 1 — the imaginary character ZZ made predictions about where the ball would land when dropped through the Tautology Machine. Unlike in Experiment 1, however, in the current study the type of the first proposition (affirmation vs. negation) in the compound statements was varied. In addition, instead of using letters, the two chutes in the Tautology Machine were marked with red and green colors. The following predictions were presented to subjects in four random orders:

Tautology 1: The ball will land on Red OR will NOT land on Red .

Tautology 2: The ball will NOT land on Red OR will land on Red.

Contradiction 1: The ball will land on Red AND will NOT land on Red.

Contradiction 2: The ball will NOT land on Red AND will land on Red.

Affirmation: The ball will land on Red.

Negation: The ball will NOT land on Red.

In this experiment there was one within-subject factor, the form of the prediction. The experimental procedure was similar to that in the first experiment. The participants made *a* *priori* evaluations and were asked if the ball should be dropped to test their *a priori* evaluation; if there was a request to drop the ball, the ball was dropped, and the participants were asked to make *a posteriori* evaluations.

Results and Discussion

As in the first experiment, children did not distinguish between logically true, logically false statements and contingent statements, exhibiting approximately equal numbers of "Not true," "True," and "Can't tell" responses (Table 3). Similar to Experiment 1, for all six propositions, all 34 children requested to drop the ball in order to test the truth status of the proposition. After the ball was actually dropped, responses presented in Table 3 changed dramatically. These new responses are presented in Table 4.

Data in Table 4 indicate that, for participants, the truth status of the predictions is a function of the ball's landings rather than the logical form of the predictions. As in the previous experiment, associations between the evaluation of the proposition as true or false and the ball's landing (each row in the table) were subjected to 2 x 2 chi-square analyses. These associations (ϕs), presented in the rightmost column of the table, are all quite high. In addition, there were high correlations between the first part of compound statements and affirmations and negations (see Table 5). These correlations suggest that regardless of the logical form, children evaluated truth status of negations and negation-first compound statements as if these were identical statements. The same pattern emerged for affirmations and affirmation-first compound statements.

Data in Tables 4 and 5 indicate that children (a) relied on the ball's landing (and not on the logical form) to determine the truth status of tautologies and contradictions, and (b) systematically ignored the second part of tautologies and contradictions, converting these statements into affirmations or negations. If the ball's landing was consistent with the first part of a compound statement, they evaluated the prediction as true; if it was consistent with the second part of the statement, they evaluated the prediction as false. Note that correlations between evaluations of the truth status of Tautology 1 vs. Tautology 2 and Contradiction 1 vs. Contradiction 2 were highly negative (see the note to Table 5). These findings demonstrate that children considered the first part of compound statements and cut the second part, independent of whether or not the second part was affirmative.

These results are consistent with our hypothesis that young children's responses are driven by the informativeness of propositions, rather than by their logical form. If a proposition appears to be totally non-informative (e.g., a tautology or a contradiction), children tend to increase its informativeness by cutting a second half of this proposition. The results also provide descriptive accounts of simplification heuristics (or "conversions") children use to increase the informativeness of non-informative propositions.

However, a number of important points are missing from the results. First, the tendency to convert non-informative propositions into more informative ones via "cutting" the second part of non-informative propositions (e.g., tautologies and contradictions) could be due to working memory limitations (i.e., young children simply forget the second part of a lengthy statement). Second, the design included only non-informative and informative forms and did not include forms that differ in degree of informativeness (e.g., conjunctions and disjunctions). Finally, the results do not allow us to rule out the possibility that "cuts" merely reflect young children's handling of highly atypical statements, such as tautologies and contradictions. These problems were addressed in Experiment 3, which included conjunctions and disjunctions. In order to test conjunctions/disjunctions, an additional state of the world was added in which a book was either opened or closed. Also, in order to limit random "noise" it was necessary to arrange a situation in which the outcomes were amenable to more precise analysis. To accomplish this, the Tautology Machine was modified so that the experimenter could surreptitiously control outcome (i.e., the landing of the ball). Finally, to examine accuracy of encoding, participants were asked to repeat each prediction to the researcher before evaluation.

EXPERIMENT 3

Method

Participants

The participants of this experiment were 38 four-and five- year-old children (*Mean age* = 4.7 years, *SD* = 0.6 year; 19 boys and 19 girls) enrolled in three childcare centers in Columbus, Ohio. Participants were selected on the basis of returning a parental consent form.

Materials

The experimental tasks were identical to those in the first experiment, but the Tautology Machine was slightly modified. The modified Tautology Machine is similar to the first machine with one exception: instead of a series of nails that function to randomize landings, a switch (occluded from participants) is moved by a lever in the back of the machine that directs the ball to one of two sides.

The procedure was similar to that in the second experiment with the following exceptions. During the warm-up phase, participants were given four pretest questions of the form presented in the experiment. Participants were eliminated from further consideration if they gave "Can't tell" responses to all questions. Six participants were eliminated on the basis of the warm-up tasks. Thirty-two children participated in the experiment. The experimenter presented ZZ, the Tautology Machine, and a book that could be either opened or closed. ZZ made predictions pertaining (1) only to the ball's landings (tautologies and contradictions) and (2) to the ball's landing and to whether the book will be opened or closed (conjunctions and disjunctions). The participants made *a priori* evaluations of ZZ's predictions, then they were asked if empirical verifications were needed, and, after the controlled outcome was obtained (e.g., the ball landed on red and the researcher did not open the book), they made *a posteriori* evaluations. The order of predictions was randomized within participants. Predictions were as follows:

Tautology1: The ball will land on Red or will NOT land on Red.

Tautology2: The ball will NOT land on Red or will land on Red.

Contradiction1: The ball will land on Red and will NOT land on Red.

Contradiction2: The ball will NOT land on Red and will land on Red.

Conjunction1: The ball will land on Red and I will open the book.

Conjunction2: The ball will land on Red and I will NOT open the book.

Disjunction1: The ball will land on Red or I will open the book.

Disjunction2: The ball will land on Red or I will NOT open the book.

Results and Discussion

As in the first experiment, children did not distinguish between logically true, logically false statements and contingent statements, exhibiting approximately equal numbers of "Not true," "True," and "Can't tell" responses. Similar to Experiment 1 and 2,in all trials, all 32 children requested to drop the ball in order to test the truth status of the proposition. The results also indicate that about 20% of responses for tautologies, conjunctions, and disjunctions, and about 7% of responses for contradictions were incorrectly encoded (i.e., they were repeated incorrectly by the child), and these responses were eliminated from further analyses.

To distinguish simplifications or conversion "cuts" from logically appropriate responses in the *a posteriori* task, a rigorous decision procedure was introduced into the analysis. To explain the procedure, let us start with an example. Suppose that the prediction is a contradiction (e.g., "will land on red and will not land on red"). Further suppose that the ball did not land on red and the child responds that the prediction was false. Such evaluation does not allow one to conclusively determine a "cut" (the child may have realized that the contradiction is always false). However, if the ball lands on red, and the child evaluates the prediction as true, then the cut could be inferred from such a response. To exclude such "logically appropriate" responses, we made sure (by manipulating the landing outcomes) that we could distinguish conversion cuts from logically appropriate responses. The predictions derived in accordance with the decision procedure are presented in Table 6.

The conversion rates are depicted on Figure 3. Data in the figure suggest than conjunctions were least likely to be cut, whereas contradictions and tautologies were most likely to be cut , and disjunctions were in-between the two extremes. A Cochran Q test, with McNemar chi-square tests used for post hoc pairwise comparisons indicated significant differences in conversion rates across the logical forms (Cochran Q (3, 32) = 22.3, p<.0001). Pairwise comparisons indicate that conjunctions were significantly less probable to be converted than disjunctions (*McNemar* (1, 37) = 4.5, p <. 05), tautologies (*McNemar* (1, 45) = 14.7, p <. 0001), and contradictions (*McNemar* (1, 46) = 28, p <. 0001), whereas disjunctions are less probable to be converted than contradictions (*McNemar* (1, 36) = 10.3, p <. 005). These data support the hypothesis , indicating that the probability of a simplification (or conversion cut) may be a function of information gain due to a verbal description.

As predicted, the results of Experiment 3 suggest that more informative propositions elicited fewer cuts than less informative ones. Young children consistently cut the second part of less informative propositions, thus converting them into more informative ones. Since only correctly encoded propositions were used in the analyses, the observed conversion cuts cannot be attributed to encoding difficulties. The results also cannot be attributed to memory limitations, in particular the tendency to focus only on the first part of a lengthy statement. The lower levels of conversions of conjunctions demonstrate that simplification cannot merely be a function of young children's inability to adequately memorize lengthy predictions.

There is one deviation from predictions that deserves a special consideration: while conversion rates for tautologies were higher than those for disjunctions (75% vs. 62%), this difference did not reach significance. This deviation might disappear with an increase of sample size (and subsequently the power of the test), or it might point to children's inability to distinguish less informative propositions (i.e., disjunctions) from non-informative propositions (i.e., tautologies). In this case, this deviation may stem from a floor effect — any indeterminate proposition (i.e., one that is compatible with more than one possibility) is likely to elicit an error.

GENERAL DISCUSSION

The major findings of the reported experiments are as follows. (1) Information gain due to a verbal description of a given logical form is predictive of conversion rates in young children: they tend to convert less informative propositions into more informative ones, and not vice versa. (2) Young children almost invariably used one conversion type — they selectively attended to the first part of less informative propositions, "cutting" the second part. And (3) Observed "cuts" are unlikely to stem from memory limitations, such as inability to process lengthy statements; the proportion of cuts was much lower in conjunctions that are as lengthy as other forms, but that are more informative. The observed cuts rather stem from a simplified representation of less informative propositions. In short, cuts are more likely when problems are less informative, and children systematically transform indeterminate problems into determinate ones by representing some parts of the problem and ignoring ("cutting") other parts. These results support our prediction and they provide descriptive accounts of simplification heuristics.

These results suggest that young children tend to construe a simplified, one-possibility representation for all the considered logical forms. Of course, such a representation biases the child against considering multiple possibilities, thus allowing a very crude analysis of incoming information. This bias affords "fast and frugal" way of information processing that is a cognitively economical, and yet not totally wrong or misleading. In most cases (with the exception of uncommonly used forms like tautologies and contradictions, and a narrow class of multi-premise deduction problems), such one-possibility representations capture a true possibility. Therefore, these simplification tendencies, while hindering reasoning in formal domains such as mathematics, science, or logic, may not have adverse affects on practical reasoning and solution of everyday problems. In particular, because they consider a true possibility, this bias may lead children to unnecessary conclusions (those that are not logically warranted), but it does not lead them to impossible or contradictory conclusions. Furthermore, this simplification bias may constitute a constraint against reaching contradictory conclusions, especially given the fact that children apparently do not understand contradictions, and, therefore might be unable to consciously eliminate contradictory conclusions.

Furthermore, such a biasing constraint on information processing may constitute a necessary prerequisite for mastering various complex domains (cf. Bjorklund & Green, 1992; Elman, 1993). Young children's representational limitations may tailor their mental representations to existing memory and processing capacities. It seems that informativeness might be a constraint that helps one to get started, but it becomes a limitation in later ages. In particular, it may limit acquisition of mathematical and logical procedures (such as proofs, which are totally uninformative, and yet are critically important).

The informativeness constraint may explain the tendency to resist deviations from one-to-one mappings between elements of the **C** set (i.e., information cues) and the **O** set (i.e., objects, categories, or state of affairs). This constraint does not represent a major cognitive limitation, however, as it can be easily overridden with appropriate training or instruction (Backscheider, & Gelman, 1995; Haygood & Bourne, 1965; Markman, 1990). For example, Haygood & Bourne (1965) demonstrated that the difficulty of learning less informative (e.g., disjunctive) concepts is present only in initial training trials. However, differences between learning of new, less informative (disjunctive) and new, more informative (conjunctive) concepts diminished markedly after subjects learned a few disjunctive concepts.

The results may have important implications for theories of problem solving and scientific reasoning. Several researchers (Acredolo & Horobin, 1987; Fay & Klahr, 1996; Horobin & Acredolo, 1989) have demonstrated that children tend to overlook empirical indeterminacy by exhibiting "positive capture" or "premature closure" heuristics. These heuristics allow children to consider a problem solved when solutions selectively matched one possibility, although children typically ignore other possible alternatives. Similarly, it has been demonstrated that children typically perform a limited search through hypothesis space by considering only a small set of possibilities (Bindra, et al. 1980; Klahr, Fay, & Dunbar, 1993; Kuhn, et al., 1995). What remained unclear is whether or not in these tasks children considered and discarded alternatives, or whether they failed even to notice these alternatives. Our results provide suggestive evidence that young children may not even consider alternatives, representing mentally just a single possibility. Of course, this contention would require further experimentation.

The reported results also shed light on some aspects of logical reasoning. Several theories of reasoning and its development are predicated upon the notion that individuals possess a set of syntactic rules or mental logic allowing them to make deductively valid inferences (Braine & Rumain, 1983; Braine, Reiser, & Rumain, 1984; Rips, 1994). According to these views, the reasoner processes the deep logical structure of the argument, extracts its logical form, and applies relevant inferential rules, ignoring the content of the argument. One such putative schema is the schema responsible for the detection of inconsistency, or contradiction (Braine, Reiser, & Rumain, 1984). The presented findings seem to undermine some of these claims with respect to young children -- these participants systematically changed the syntactic form of the contradiction, without detecting an inconsistency. Of course, it could be argued that children changed the form of the contradiction by cutting it, thus indicating that they detected the inconsistency. However, the fact that contradictions were treated in the same manner as tautologies and disjunctions undermines such a counter argument. Present findings also dovetail with those of other researchers who have demonstrated that reasoners balk at logically-warranted but non-informative conclusions, such as inferring that "*Some people are not law-abiding citizens* or *I like tea"* from the premise "*Some people are not law-abiding citizens.*" They rather infer more informative but not logically-warranted conclusions, like "*Crime is on the rise*." (see Harman, 1996; Johnson-Laird & Byrne, 1992, for discussions).

It could be counter argued, of course, that the observed results have nothing to do with information gain, but that they rather stem from either overall confusion of young children, or from a relative atypicality of tautologies, contradictions, and disjunctions. The confusion explanation does not seem plausible, because errors exhibit systematic patterns rather than random noise. We, therefore, proceed to "atypicality" arguments. To discuss these arguments, we deem it necessary to consider first, <u>in which respect</u> one might consider some propositions more atypical than others.

First, atypicality may pertain to the logical form — tautologies and contradictions have an atypical logical form that conjoins an affirmation and its negation in one sentence. Second, atypicality may pertain to pragmatics — disjunction and conjunction have atypical pragmatics conjoining different topics in one sentence. Third, there might be atypicality of a logical connective (e.g., "or" could be claimed to be more atypical than "and"), in which case tautologies and disjunctions are more atypical than contradictions and conjunctions. Fourth, there could be semantic atypicality of indeterminate and non-informative propositions, in which case tautologies, contradictions, and disjucntions are less typical than conjunctions. These forms are less typical than conjunctions in the sense that they run counter to children's assumptions of the maximal information gain. We will address each of these possibilities and consider patterns of errors that should have been generated by each of these factors.

If observed errors (i.e., conversion cuts) stem from atypicality of the logical form, then reported errors should be limited to tautologies and contradictions. Of course, this explanation would require children to exhibit some understanding of the logical form. On the contrary, not only were errors observed with disjunctions, neither the current experiments (i.e., responses to a priori evaluations), nor previous research suggest that young children are sensitive to the logical form of a proposition (Osherson & Markman, 1975) or an argument (Markovits, Schleifer, Fortier, 1989).

If observed errors stem from atypical pragmatics, that is, conjoining different, unrelated topics in one sentence (e.g., Lakoff, 1971), then the disjunctions and conjunctions in this experiment should have elicited more errors than tautologies and contradictions, because the latter two forms concern one topic rather than two. On the contrary, conjunctions, which concern two topics, elicited fewer errors than the other forms.

If atypicality of a logical connective was the main reason for errors, with "and" being more typical than "or," then tautologies and disjunctions should have elicited more errors than conjunctions and contradictions. While typicality of "and" versus "or" remains unknown (we were unable to locate a single paper examining this issue), there is evidence that disjunctions are as comprehensible to young children as conjunctions (Johansson & Sjolin, 1975). In addition, the pattern of errors predicted by atypicality of the logical connective deviates from the observed pattern.

Finally, observed errors could have stemmed from semantic atypicality of indeterminate propositions, as indeterminate propositions violate the full-determinacy or the maximal information value assumption. In this case tautologies, contradictions, and disjunctions are less typical than conjunctions, and the former three forms should have elicited more errors than the latter. This explanation is exactly what we had hypothesized and this pattern of errors was indeed observed in our experiments.

Therefore, it seems likely that the observed errors stem from "semantic atypicality" of indeterminate propositions, which violate expectations of full determinacy and maximal information value. When such violations of full determinacy take place, young children respond as if they were maximizing information gain, often "cutting" or ignoring parts of indeterminate statements.

In short, presented evidence supports the prediction that propositions yielding larger information gain are more likely to be processed veridically, whereas low informative propositions are likely to be simplified. The most frequently observed simplification heuristics used by young children is a "cut" -- selective focussing on the first part of low informative proposition, while ignoring the second part.

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Table 1

Percent of participants' *a priori* responses to propositions differing in their logical form (Experiment 1).

	Response types		
	Not true	True	Can't tell
Tautology	45.2	8.1	46.7
Contradiction	43.5	12.9	43.6
Affirmation	30.6	29.0	40.4
Negation	32.3	27.4	40.3

Table 2

Numbers of participants evaluating predictions as true or false by different landings of the ball (Experiment 1).

	Ball's landings and *a posteriori* evaluations				Associations between *a posteriori* evaluations and ball's landings
	Lands on A		Lands on B		
Predictions	True	False	True	False	
Tautology (The ball will land on A or will not land on A)	12	2	1	12	$\phi = .78; \chi^2(1) = 16.4$*
Contradiction (The ball will land on A and will not land on A)	11	1	1	14	$\phi = .85; \chi^2(1) = 19.5$*
Affirmation (The ball will land on A)	11	2	0	14	$\phi = .86; \chi^2(1) = 20$*
Negation (The ball will not land on A)	1	15	11	0	$\phi = -.93; \chi^2(1) = 23.1$*

Note: *$p < .0001$.

Table 3

Percent of participants' a priori evaluations of propositions differing in their logical form (Experiment 2).

	Response types		
	Not true	True	Can not tell
Tautology1	17.7	35.3	47.00
Tautology2	8.8	26.47	64.71
Contradiction1	17.65	32.35	50.00
Contradiction2	17.65	38.24	44.12
Affirmation	14.71	50.00	35.29
Negation	23.53	44.12	32.35

Table 4

Numbers of participants evaluating predictions as true or false by different landings of the ball (*a posteriori* evaluations), Experiment 2.

	Ball's landings and *a posteriori* evaluations				
	Lands on Red		Lands on Green		
Predictions	True	False	True	False	Associations between *a posteriori* evaluations and ball's landings
Tautology1 (The ball will land on Red or will NOT land on Red)	20	1	0	10	$\phi = .93; \chi^2(1) = 26.8$*
Tautology2 (The ball will NOT land on Red or will land on Red)	0	13	14	1	$\phi = -.93; \chi^2(1) = 24.3$*
Contradiction1 (The ball will land on Red and will NOT land on Red)	16	0	0	16	$\phi = 1; \chi^2(1) = 32$*
Contradiction2 (The ball will NOT land on Red and will land on Red)	1	15	17	0	$\phi = -.94; \chi^2(1) = 29.2$*
Affirmation (The ball will land on Red)	13	0	2	19	$\phi = .89; \chi^2(1) = 26.7$*
Negation (The ball will NOT land on Red)	0	11	20	2	$\phi = -.88; \chi^2(1) = 25.4$*

Note: * p <.0001.

Table 5

Correlations between evaluation of the truth status of empirical statements and logical constants after dropping the ball (Experiment 2).

	Affirmation	Negation
Contradiction1 (Negation first)[1]	-.99	.89
Contradiction 2 (Affirmation first)[2]	.99	-.86
Tautology1 (Negation first)[3]	-.81	.84
Tautology 2 (Affirmation first)[4]	.81	-.82

Note: $\phi_{1,2}$ = -.9; $\phi_{3,4}$ = -.76.

Table 6

ZZ's predictions, controlled outcomes, and response representing conversions ("cuts")

Prediction	Controlled outcome	Logically appropriate response	Response representing a conversion "cut"
Tautology1 (The ball will land on Red or will NOT land on Red)	Not red	True	False
Tautology2 (The ball will NOT land on Red or will land on Red)	Red	True	False
Contradiction1 (The ball will land on Red and will NOT land on Red)	Red	False	True
Contradiction2 (The ball will NOT land on Red and will land on Red)	Not red	False	True
Conjunction1 (The ball will land on Red and I will open the book)	Red & not book	False	True
Conjunction2 (The ball will land on Red and I will NOT open the book)	Red & book	False	True
Disjunction1 (The ball will land on Red or I will open the book)	Not red & book	True	False
Disjunction2 (The ball will land on Red or I will NOT open the book)	Not red & not book	True	False

Author Note

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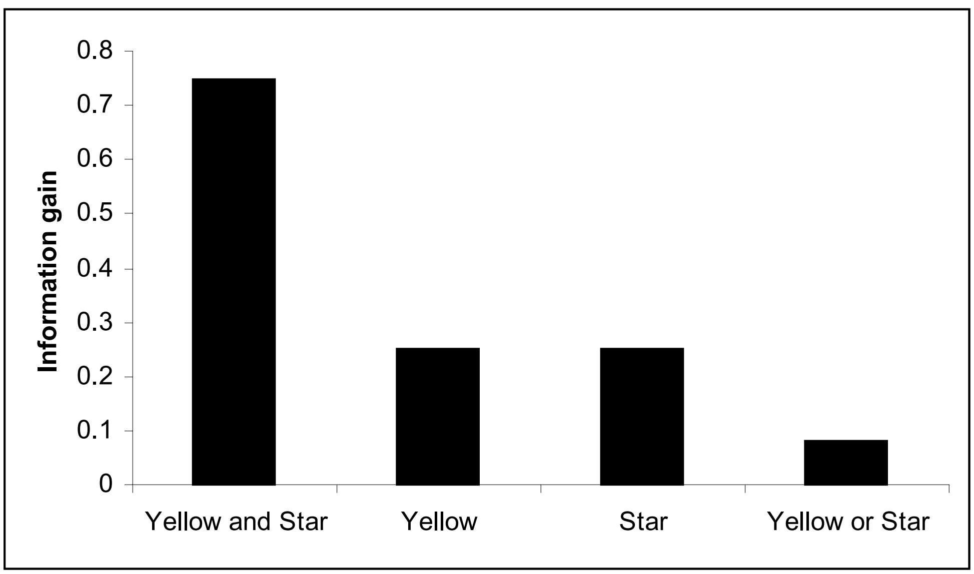
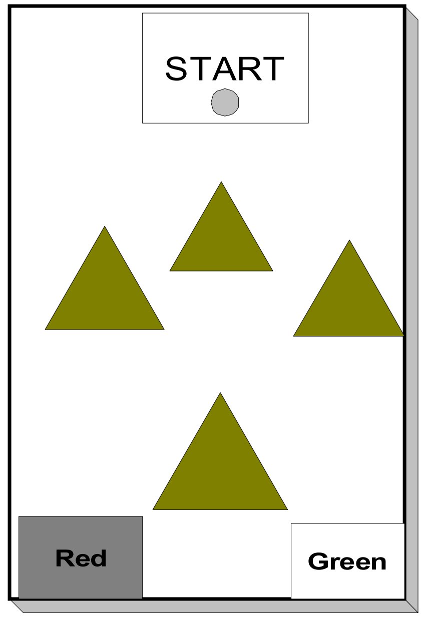
Figure Captions

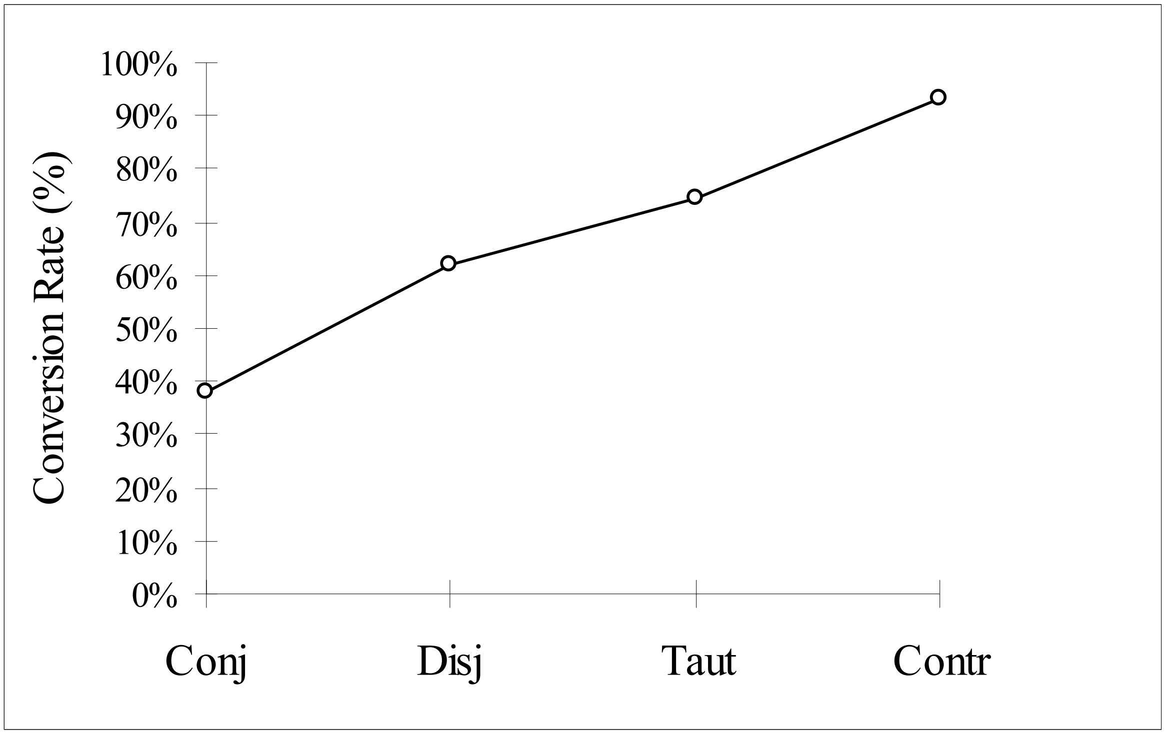
Figure 1. Information gain due to verbal descriptions of different form.

Figure 2. Layout of the "Tautology Machine."

Figure 3. Percent of conversion “cuts” by types of propositions, Experiment 3.


Information gain
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Yellow and Star
Yellow
Star
Yellow or Star


START
Red
Green


Conversion Rate (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Conj
Disj
Taut
Contr