Some Common Causes of Literacy and Numeracy

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The "primacy of reading" hypothesis as the explanation of the high correlation between children's competencies in literacy and numeracy is rejected. Instead a "primacy of speech perception" hypothesis is examined. Analysis-by-synthesis speech recognition procedures are acquired in early childhood prior to the development of basic literacy and numeracy. Yet, the logic of the analysis-by-synthesis procedure is common to both arithmetic problem solving and reading comprehension. In structural terms, competencies in all three decoding strategies are dependent on the child's ability to intuitively use phonetic, syntactic, and semantic rule-following or cueing strategies. Thus, it was found that all the covariation between reading and numeration for a sample of grade four children was accounted for by these strategies as mediated by the school dependent basic language skills. Similarly, the research confirmed the reciprocal interrelationship between literacy and numeracy. An elasticities analysis demonstrated, however, that reading and numeration, though highly responsive to one another, were not particularly responsive to changes in children's cueing strategies or basic skills performances. Some suggestions for further research were made in the light of this unanticipated finding.

On rejette l'hypothèse du rôle primordial de la lecture comme explication du rapport très étroit qui existe chez l'enfant entre savoir lire et écrire et savoir compter. On se tourne plutôt vers l'hypothèse du rôle primordial de la perception des paroles. Très jeune, avant d'avoir commencé à apprendre à lire, écrire et compter, l'enfant acquiert des procédés d'analyse par synthèse pour reconnaître les paroles. Pourtant, la logique des procédés d'analyse par synthèse est la même que celle de la résolution des problèmes d'arithmétique et que celle de la compréhension des textes. Structurellement, la compétence dans ces trois modes de décodage dépend de la capacité qu'a l'enfant de recourir intuitivement à des "stratégies" phonétiques, syntaxiques et sémantiques d'observation de règles et de découverte de réponses. C'est ainsi qu'on a constaté que la covariation dans la lecture et la numération, chez un échantillon d'élèves de quatrième année, s'expliquait totalement par ces "stratégies" qui s'inspirent des techniques fondamentales du langage et qui sont utilisées dans les écoles. De même, la recherche a confirmé les rapports réciproques qui existent entre savoir lire et écrire et savoir compter. Cependant, une analyse des "élasticités" a montré que la lecture et la numération, bien qu'elles réagissent beaucoup l'une sur l'autre, ne réagissent pas de façon particulière à la modification des stratégies de réponse de l'enfant ni à la modification de son utilisation des techniques de base. Devant cette constatation inattendue, on indique quelques voies qui s'ouvrent à la recherche.

INTRODUCTION

The Problem

The school performances of elementary school children in literacy and numeracy covary. That is, there is a high correlation between reading and numeration, such that children in the early grades of schooling who perform well in reading also tend to perform well in arithmetic.[1] The reasons for this are addressed in this study.

Actually, the correlations between reading and arithmetic problem solving for 10-year-olds hover around the 0.6 level. As a pupil moves from the middle grades to junior secondary school the association strengthens. Thus, the correlation between reading and mathematics achievements for 14-year-olds is around 0.7. For 10-year-olds about 36% of the variance in one skill is explained by variance in the other; for 14-year-olds almost half the variance may be shared jointly.

The traditional explanation

The strong correlation between literacy and numeracy is well known by teachers; further, it is believed to be well understood. In general, then, it is not regarded as problematic. The conventional wisdom goes something like this: If the pupil cannot read very well he is not likely to be very proficient in solving verbal arithmetic problems. This is understood to be the case because reading is a necessary, though not sufficient, condition to understanding the problem in the first place. If the problem is not understood, how can it be solved?

For example, consider a problem of the kind: In the time that Jane can sharpen two pencils, Mary can sharpen three. When Mary has sharpened 12 pencils how many will Jane have done?

Many 10-year-olds cannot solve this problem correctly. The teacher's dilemma is whether the pupil is unable to solve the problem because he is weak at arithmetic or because he cannot read the question meaningfully. Or perhaps the pupil is weak at both skills. According to the traditional explanation, because there is a reading component to arithmetic problem solving, then reading is a common factor. If the pupil who failed to solve the arithmetic problem also falls below the criterion of mastery in reading comprehension, then it is assumed that reading is the major problem, not numeration. Thus, much of the research on the mathematical problem-solving behavior of children has emphasized reading as a major factor predictive of arithmetical problem solving. We shall refer to this as "the primacy of reading" hypothesis.

Rejection of the traditional explanation

Despite the numerous studies which have focussed on the magnitude of the impact of reading performance on the solution of verbal arithmetic problems, the results have been equivocal. Many of the experimental models have also been misspecified. In a recent review of this research, Hollander (1978, p. 68) concluded that information on the problem was scanty and inconclusive at best. Hollander identified 12 studies in which either general reading ability or specific reading skills were used as predictors of arithmetic problem-solving ability. All found gains in reading associated with concomitant gains in arithmetic performance; hence, most conclusions were of the kind — reading deficiencies hinder abstract thinking as represented by computational skill and problem-solving ability.

The notion seems clear enough: language or literacy handicaps in general will inhibit numeration performance. The results of research on the most verbally deprived of all children — the congenitally deaf — do not, however, support this conclusion. Vernon (1968) points out that while deaf children score well below normal children on verbal tests, "the research of the past fifty years . . . indicates that when there are no complicating multiple handicaps, the deaf and hard-of-hearing function at approximately the same IQ level on performance tests as do the hearing" (p. 9).

If the traditional explanation were correct it would follow that because reading is logically prior to computational accuracy, then reading would be a better predictor of numeration than the other way round. Such a feedback model is premised on the self-evident belief that achievment stimulates achievement. Nevertheless, at the time of writing a review of the research has yielded only one example of a double outcome, literacy-numeracy model, specified in such a way that its functional or mathematical form is isomorphic to explanations of the "X affects Y, but Y may also affect X" variety. This was Hauser's (1972, p. 78) study, which used a sample of Tennessee high school seniors. The results of Hauser's research were supportive of the primacy of reading hypothesis, but it would be imprudent to generalize the findings of a single study on high school youth to elementary school children.

In the period 1976-77 the Australian Council for Educational Research released three volumes of a study on literacy and numeracy (Keeves et al., 1976; Bourke & Lewis, 1976; Bourke & Keeves, 1977). The results of the Australian national survey did not support the primacy of reading explanation. If the explanation were true it would be predicted that students failing to achieve the criterion of mastery in reading would probably fail to achieve the criterion of mastery in numeration. The prediction stems directly from the primacy of reading hypothesis; because reading is common to both skills, and because reading is logically prior to comprehension of verbal arithmetic problems, then reading deficits would handicap numeration more than numeration deficits would handicap reading.

Such was not the case. In fact, for 10-year-olds the reverse was found. Bourke (1977, p. 105) reports that 3,182 10-year-olds from the national probability sample failed to achieve the criterion of mastery in reading; but of these more achieved mastery in numeration (1,790 or 56%) than failed to achieve mastery in numeration (1,392 or 44%). In following up this finding Bourke (1977) re-examined the reading-numeration relationship after partialling out the effects of selected verbal subtests; that is, after controlling for their effects. He found that "when sub-tests were considered . . . the relationships between mastery of Reading and Numeration Tests were not dependent on a reading component of the Numeration Tests" (p. 106).

Purposes

We question, then, the authenticity of the primary of reading hypothesis, at least as far as elementary school achievement is concerned. This calls for the formulation of a more accurately specified literacy-numeracy model; that is, for a new theory. Few would deny the importance of the problem. Most of the goals of people everywhere require education as the chief means of reaching them. For example, the initiation of the young into the major modes of understanding characteristic of national cultures is probably a necessary condition for the acquisition of self-respect, and is probably necessary for successful participation in daily life. Such goals are highly dependent on the acquisition of functional literacy and numeracy.

Concern centres on the question: What are the common causes of the covariation between literacy and numeracy? Thus, a new model needs to be designed with the null hypothesis that the source variables will account for this covariation. Accurate model specification also calls for a feedback effects model; namely, that the literacy-numeracy relationship is reciprocal. Thirdly, if the common causes can be identified, it would be desirable to find out the extent of the responsiveness of literacy and numeracy to these causes. Presumably the magnitude of the responsiveness would provide some indication of the policy relevance of the model.

Three interdependent questions are to be addressed in the remainder of the paper: (a) What are the common causes of literacy and numeracy? (b) To what extent are performances in literacy and numeracy mutually reinforcing or reciprocal? and (c) To what extent are school performances in reading and numeration responsive to their identifiable common causes?

THEORETICAL FRAMEWORK

Overriding assumptions

It can be readily assumed that since literacy and numeracy performances covary the two skills have common determinants. It is also assumed that oracy precedes literacy and numeracy, and that oracy in turn is dependent on speech perception. "Before he speaks," say Gibson and Levin (1975), "the child is semantically wise" (p. 137). Thus, the comprehension of speech or receptive language precedes productive speech; and, likewise, the comprehension and production of speech precedes learning to read (cf. Siegal, 1978, p. 59).

It is posited, then, that there are conditional laws of language development in the sense that under the given conditions and notwithstanding development overlap, phonological-morphological developments precede exponential semantic-syntactic developments in early childhood. The conditions governing the resource transformations from one stage of language development to another seem well understood (c.f. Bronfenbrenner, 1979; Bruner & Garton, 1978; McNeill, 1970; Slobin, 1971).

At any given time in early childhood the semantic-syntactic developments will feedback to the phonological-morphological and vice-versa. These mutually reinforcing relationships will prove predictive, though not deterministic, causes of language developments at later points in time. The resultant structure of language factor interrelationships would constitute a helix, though the specific structure of a model of childhood language development remains unknown.

Analysis-by-synethesis decoding

A model for the prediction of the covariation between literacy and numeracy can take speech recognition as its starting point. It is not until the child is able to fluently decode verbal messages from others that literacy and numeracy become possible. The thesis, then, is that both reading comprehension and numeration have common roots in speech perception. The task, of course, is to identify these roots.

Speech recognition

It can be shown that a cross-section of the speech recognition process begins with an accoustic signal or series of signals from a speaker (such as a sentence or similar stretch of sound) and ends with the listener's confirmation or nonconfirmation of the signal (cf. Halle & Stevens, 1964, 1967). If the signal is confirmed the successful synthesis will be followed by preliminary analysis of the next signal prior to the next synthesis and so on. Signal selection is based on the exclusion from consideration of all but those input items which conform to known language rules and background experience. The language rules constrain the possible structure of the phoneme sequence.

Thus, signals or messages are governed by intuitively invoked language rules which constitute the cues triggering the listener's decoding strategy. Phonetic rules govern the sounds uttered; semantic rules govern the words spoken; and syntactic rules govern the word ordering. The comprehension of speech necessitates that the listener invoke these rules in order to hypothesize, predict, or guess at the meaning of the discourse. The hypotheses are confirmed by verification against the original signals so that the prediction of meaning is checked by a feedback mechanism. Lack of confirmation may necessitate replication of the procedure, though listeners are not free to make an infinite number of guesses. As Neisser

(1976, p. 32) points out, listening necessarily involves the ability to generate hypotheses that are unlikely to be disconfirmed. This is borne out by Bruner's (1978) research, which shows that infants, when learning words, receive a great deal of guidance by their private tutors (mothers). The tutors are at pains to provide the tell-tale clues which virtually ensure correct hypothesizing.

Perhaps the central notion in this model of speech perception is that involving the making of predictions or inferences about the meaning of the discourse based on the intuitive application of phonological, semantic, and syntactic language rules. Knowledge of these rules constrains the number of plausible predictions. Verification of the deduction from the prediction constitutes synthesis; further inferences are made from the fusion of the new synthesis with the next accoustic signal, and so the pattern continues until the message has been received in its entirety.

Numerical problem solving

Halle and Stevens (1964) note that "the task of developing suitable speech recognition strategies is related to . . . a general problem in mathematics — that of discovering the shortest proof of a theorem when a set of axioms is given" (p. 612). The suggestion here is that aspects of both speech recognition and mathematical problem solving have a common underlying logic. Thus, it is instructive to enquire as to whether, and to what extent, psycholinguistic rules play a role in mathematical problem solving.

Consider the following algebraic word problem adapted from Paige and Simon (1966):[2]

If the number of papers Tom delivers is twice the square of 20 percent of the number of homes and apartment dwellings in the neighbourhood, and the number of homes and apartment dwellings is 20, what is the number of papers Tom delivers? (p. 53)

To solve the problem it is necessary to translate it from the common language statements in which it is composed into algebraic statements or equations; that is, from a symbolic system governed by one set of rules to a different-in-degree-of-emphasis rule governed symbolic system.[3] Such a translation is presented in step-by-step form in Table 1, to illustrate the powerful and essential role of semantic and syntactic strategies in mathematics.

It is seen from Table 1 that the substitution of algebraic symbols for common language statements involves the identification of meanings (semantics). The essential meanings are the mathematical ones: "two times" for twice, "square" for square of, and "percent" for percent. It can be seen, too, that it is important to distinguish between words which carry meanings and words which have grammatical functions — the operators (op.), verbs, pronouns, and delimiters (DLM). In the selected

TABLE 1

An Edited Version of the Translation of a Verbal Algebraic Problem from Common Language Statements to Algebraic Statements

Common Language Statements	*Semantic Elements*	*Syntactic Elements*	*Algebraic Statements*	*No. Units*
The number of papers Tom delivers	Substantive meaning to be translated into variable name	—	x_1 (an unknown)	1
is	—	verb	= (arithmetic operator)	2
twice	mathematical meaning	—	two times, or 2* (* = times)	3
the square of	mathematical meaning	—	square (. . .)^2	4
20 percent	mathematical meaning	—	two tenths, or, 0.2	5
of	—	functional operator	times, or * (cf. unit #3)	6
the number of homes and apartment dwellings in the neighbourhood	substantive meaning to be translated into variable name	—	x_2 (another unknown)	7
, and	—	conjunction	indicates end of clause	8
the number of homes and apartment dwellings in the neighbourhood	same substantive meaning as unit #7 variable	—	see unit #7	9
is	—	verb	= (arithmetic operator)	10
20:	mathematical meaning	—	20	11
what:	—	functional operator	?	12
is:	—	verb	= (arithmetic operator)	13
the number of papers Tom delivers?	same substantive meaning as unit #1	—	see unit #1	14

algebraic problem, the syntax can be identified by "tagging" the relevant words as follows:

The number (of/op.) papers Tom (delivers/verb) is 2 (times/op.) the (square/op.) (of/op.) 20 (percent/op.) (of/op.) the number (of/op.) homes and apartment dwellings (in/op.) the neighbourhood and the number (of/op.) homes and apartment dwellings (is/verb) 20, (what/Q word) (is/verb) the number (of/op.) papers Tom (delivers/verb) (Q mark/DLM).

This leaves words with substantive but non-numerical meanings. The problem solver must understand the mathematical convention that applies to these substantive terms; for example, "the number of papers Tom delivers" or "the number of homes . . . neighbourhood" are translatable into variable names of the x_1, x_2 variety. Can there be much doubt that in such problems the solution is grounded in an understanding of the rules of syntax and semantics?

Similarly, can there be much doubt that to solve supposedly non verbal arithmetic problems of the $(2(7-3)-6)^2$ variety involves the covert but spontaneous verbalization of the problem? Surely it is the type of spontaneous verbal mediation of the problem that the mathematical problem-solving researchers are trying to identify through application of their introspective/retrospective techniques (cf. Blake, 1976; Kantowski, 1977; Pereira-Mendoza, 1979). That the path to numerical problem solving solutions is characterized by, among other things, regular analysis-by-synthesis patterns parallel to those used in speech recognition is explicitly recognized by some mathematics education researchers. Thus, Kantowski (1977) notes that "evidence of regular patterns of analysis-and-synthesis (deduction inferred from hypotheses followed by synthesis, then by further inferences from the new synthesis and so forth) was noted in the solutions of problems with scores above the median" (p. 166).

Reading comprehension

Just as prediction, hypothesizing, or guessing were found to be the basis of speech perception and arithmetical problem solving, so they are the basis of all comprehension (Smith, 1978). Every activity, even the aesthetic appreciation of music (Meyer, 1957), is dependent on our expectations and anticipations about that activity and reading is no exception. A theory which stresses the importance of prediction procedures or hypothesis testing in reading is usually referred to as an analysis-by-synthesis model (Neisser, 1967) or a "psycholinguistic guessing game" model (Goodman, 1967).

Basically, these theories claim that the reader utilizes his knowledge of the world and of language as well as his knowledge of the task at hand to analyze the situation in which he finds himself. As he begins to analyze the print he selects the cues to attend to or focus on. Once the appropriate cues are selected, in accordance with what he thinks he ought to find in the message, he tries to associate meaning with them by comparing the selected print information to what he already knows, generalizing the results to fit the new situation he is reading about, and synthesizing or bringing together the results of the new situation and his already existing knowledge. As he synthesizes the new ideas he assimilates or incorporates them into his knowledge domain and is then able to make another prediction of what will likely follow, based upon the synthesizing and assimilation of his old and new information.

If the reading activity takes place in a situation where his knowledge background is not adequate for the demands that the print will make, he will be unable to pose adequate questions or determine appropriate expectations (that is, to predict) and, hence, will be unable to comprehend.

Not only is a reader dependent upon background knowledge when he reads, but also he is equally dependent upon his knowledge of language and the meaning conveyed through language. As a reader reads he has certain expectations that what he reads will sound like meaningful language; that is, readers intuitively anticipate that what they read will be grammatically acceptable and meaningful. As he begins reading, the reader selects graphic (print) cues in accordance with these expectations and uses this information to formulate a "guess" or to make a prediction about the intent of the message. If, when the reader tries to associate these cues with his knowledge of meaningful language, the comparison is favorable, he is able to synthesize the information and check it out with subsequent information in the text. If further text information confirms his synthesis, the expectation or prediction of what ought to be there is confirmed and he can make a further prediction of what is likely to occur next. If the prediction is not consistent with his notion of meaningful language as well as with textual information, the reader recognizes he has misread some of the information and he must therefore reread or reinspect the print in order to alter his choice of cues, this time based on a different expectation of what he will find. The reader, then, is constantly feeding back the information received from the cues selected in the print to see whether it confirms his anticipatory hunches, guesses, or hypotheses. If the feedback is negative he will have to go back to reread for more information.

Until recently these processes were largely covert and unobservable, but miscue analysis techniques developed by Y. Goodman and Burke (1972) have facilitated the measurement of the cueing strategies as proxies for these processes.

All this is not to say that the analysis-by-synthesis model necessarily has wide acceptance. The fact is that the theory has been severely criticized on at least two grounds. First, the theory has been found lacking in specificity, and, therefore, according to Gibson and Levin (1975) "the theory is too imprecise to account for all kinds of reading" (p. 453). We would regard this as naive criticism, since it lacks awareness of the incremental model building tradition characteristic of scientific advance — advance documented by the historian of science. Further, it fails to consider the self-correcting feature of model building; namely, that authentic models are falsifiable and hence replicable. Theories do not emerge fully developed; rather the basic relationships have to be extended, modified, and elaborated. There is constant interplay between theory and data, and the whole process, whether in physics or reading, is often much less precise than the researcher would have us believe (Russell, 1948, p. 321).

In the second place the theory has been found lacking in predictability (see Harker, 1973). The results presented in this paper, however, discount this criticism — though the results are far from being deterministic. Elsewhere, Beebe (1980) has estimated the basic equations of the psycholinguistic model developed by the Goodman-Goodman-Burke group (Goodman & Burke, 1968; Goodman & Burke, 1969; Y. Goodman, 1971) and demonstrated their powerful predictive qualities. In a recent paper Beebe and Bulcock (1978) developed an extended and elaborated analysis-by-synthesis model of both reading and retelling which gave both a good fit to the data and had high predictability.

Transforming linguistic resources

The teacher does not leave the transformation of a child's linguistic resources into reading competencies to chance. Rather, teachers initiate students into the basic skills; that is, they extend the child's meaning vocabulary, and develop language skills (spelling, punctuation, capitalization, and language usage) and work study skills (use of maps, graphs, tables, illustration, and reference materials) as aids to reading. Thus, if the child's psycholinguistic resources are regarded as primary resources and literacy and numeracy as secondary resources, then the basic skills may be regarded as the mediating linkages or mechanisms for converting the primary into the secondary resources.

Literacy-numeracy models

It was shown above that the analysis-by-synthesis model was common to both theories of numeration and theories of reading. How does an observer know whether a reader or problem solver is on the inside of the analysis-by-synthesis decoding procedure? The answer would seem to be that it depends on how fluent the reader/problem solver is in utilizing the appropriate language rules. The actual process underlying the cueing strategies cannot be observed but only inferred from the observation of children's mistakes in problem solving or miscues in reading, which can be measured as described in Y. Goodman and Burke's (1972) Reading Miscue Inventory.

The problem stated in the form of three questions in the introduction calls for the estimation of four models, the first three of which can be integrated into one (see Figure 1). They are: (a) a prediction model of early reading; (b) a prediction model of early numeration; (c) a covariation model; and (d) a reciprocal effects model. The estimated structural parameters of the fourth model can be used to calculate the model elasticities, thereby providing unambiguous answers to the third question.

In each model the source variables — graphic, phonic, syntactic, and semantic cueing strategies — are mediated in their effects on reading and numeration by the basic skills — vocabulary, language skills, and work study skills. Four major hypotheses are generated: (1) that the basic skills will mediate the effects of cueing strategies on reading comprehension and arithmetic problem solving performance; (2) that both arithmetical problem solving and reading at the Grade 4 level will be more dependent on syntactic and semantic strategies than the graphic and phonic; (3) that the linguistic rule-following strategies and basic skills will account for the covariation between literacy and numeracy; and (4) that the relationship between reading and numeration will be reciprocal.

METHOD

Sample

Ninety-four Grade 4 pupils enrolled in two urban schools constituted the case base. Since it was necessary for all the subjects to be able to read the same passage, yet make mistakes, only those who were able to comprehend at least 75% of what they read on Maze 5 and 6 of the Guthrie-Siefert Maze Task were chosen. Seventy-four percent of the Grade 4 children were selected — 46 boys and 48 girls.

Materials

The instrument used for classifying miscues, hence for measuring graphic, phonic, syntax, and semantic variables, was the Reading Miscue Inventory (RMI) developed by Y. Goodman and Burke (1972).

The Guthrie-Siefert Maze Task is a modification of the cloze procedure. Instead of inserting a word in a blank the reader must select one of three alternative words that are embedded for every fifth word in the story. The percentage of correct selections indicates the degree of comprehension. Guthrie (1973) describes the psychometric properties of the instrument which correlates at the 0.82 level with the Gates-MacGinitie Comprehension Subtest.

The reading comprehension, arithmetic problem solving, language skills, and work-study skills measures were grade equivalent scores obtained from the administration of the Canadian Tests of Basic Skills (King et al., 1973). King et al. (1975) report split half reliabilities for reading and arithmetic subtests of 0.92 and 0.90 respectively. The vocabulary, language skills, and work-study skills subtests were factor analyzed in order to construct an outward indicator or reflective latent variable called "basic skills." It had an omega reliability of 0.854 (Heise & Bohrnstedt, 1970, p. 115).

Procedures

Step one in the data gathering procedure involved oral reading of the selected passage ("Space Pet"), the retelling of the story by the subject, and the audio-taping of the procedures. The second step involved replaying the tape in order to mark each miscue. A week later the local school authority administered the Canadian Tests of Basic Skills.

Cueing strategy variables

RMI procedures were followed in the data gathering and coding phase of the research. The "graphic miscue" variable represented a proportionate measure of each respondent's miscues which lacked graphic similarity. The proportion was obtained by dividing the number of dissimilar responses by the total number of responses in the single-word or non-word substitution categories; hence, the higher the score the lower the graphic similarity performance. The same procedure was used in constructing the "phonic miscue," which represents the proportion of miscues lacking phonic similarity.

Only syntactic weaknesses were used in calculating an individual's unacceptable "syntactic miscues," and, similarly, only comprehension losses were used in calculating unacceptable "semantic miscues." Both were converted into proportions by dividing the unaccepted miscues by the respondent's total number of miscues minus the number of corrections. Thus, the variables were called the proportion of unacceptable synatactic miscues and proportion of unacceptable semantic miscues respectively.

Two inward indicator latent variables were derived from the cueing strategy variables through application of factor analysis using an oblique rotation. Their omega reliabilities were 0.918 for the grapho-phonic composite and 0.723 for the syntactic-semantic composite. See Figure 1 for the structure of the outer relationships of these variables.

Estimating procedures

Because complex models of the kind specified in the theory section and illustrated in Figure 1 are frequently plagued by multicollinearity — that is, the condition where predictor vectors depart from orthogonality — two methods of coping with the problem were used. First, latent predictor variables were constructed which include within themselves much

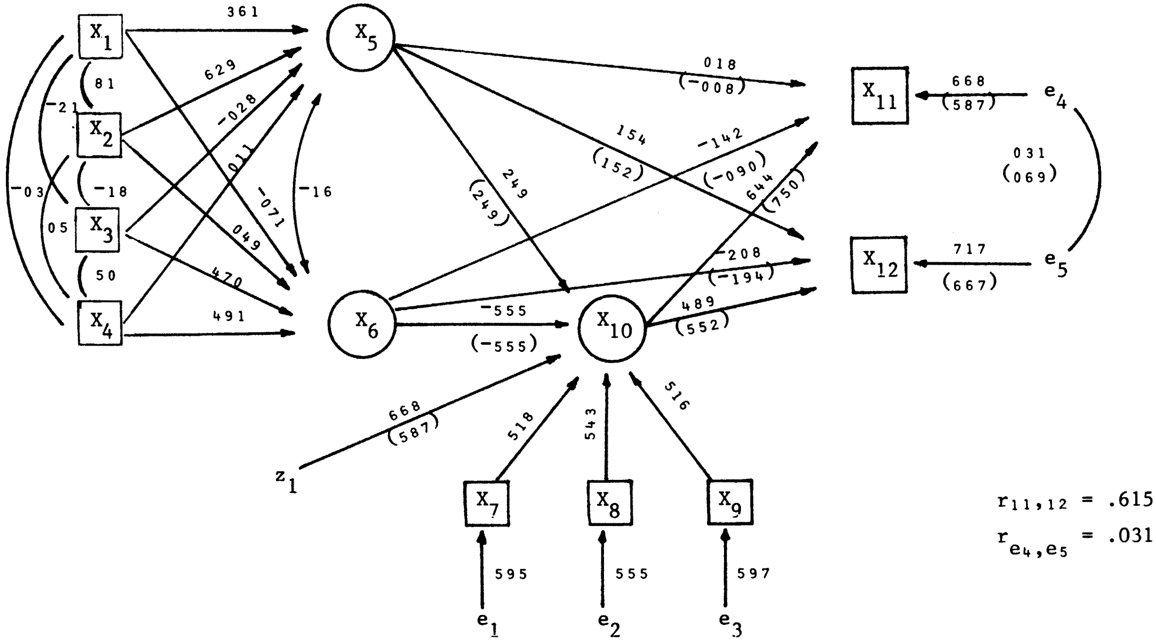

FIGURE 1

Structure of the Covariance Model

NOTE: Variable identifications: X_1=proportion of miscues lacking graphic similarity, X_2=proportion of miscues lacking phonetic similarity, X_3=proportion of unacceptable semantic miscues, X_4=proportion of unacceptable syntactic miscues, X_5=grapho-phonic cueing strategy deficiency, X_6=syntactic-semantic cueing strategy deficiency, X_7=vocabulary, X_8=language skills, X_9=work study skills, X_{10}=basic skills, X_{11}=reading comprehension, X_{12}= mathematics achievement. OLS estimates are below the normalization regression estimates in each instance. The latent variables are enclosed in circles; observed variables are in boxes. Decimal points have been omitted.

of the multicollinearity. Second, biased reduced-variance estimators were used based on application of the variance normalization criterion.

The second technique is new. The statistical theory underlying its use was developed by Lee (1979) and Lee and Luk (1979). For several applications of its use see Bulcock (1979), Bulcock et al. (1980), or Bulcock and Beebe (1980). In this paper both the normalization regression analysis and ordinary least squares (OLS) regression results are presented adjacent to each other for ease of comparison (see Tables 3 and 4).

RESULTS

Covariance model findings

The parameters of all the models in the study were estimated from the appropriate matrices of the correlation coefficients presented in Table 2. All conclusions were drawn from interpreting the results from normalization regression analyses. The covariance model findings are shown graphically in Figure 1 and the detailed estimates presented in Table 3. Note in Table 3 that D_{max} stands for the degree of collinearitv in the model and can be interpreted as follows: zero for no collinearity and one for perfect collinearity. In our experience collinearity of less than 0.5, though undesirable, tends not to be too serious in so far as educational models are concerned. Note also that in Table 3 k_N (read "normalization k") represents the magnitude of the biasing parameter. The reduction in the total variance of the estimates is highest for low k. In normalization regression the variance inflation is reduced through normalizing the variance inflation factor such that it is equal to one.

The most important covariance model finding concerned the correlation between the residuals which came to .031 (Table 3), and which surely indicates that nearly all the covariance between reading and numeration was accounted for by the common causes — the graphophonic and syntactic-semantic strategies and basic skills. Note, too, that the model is powerfully predictive of both reading comprehension and numeration — accounting for 55 and 48% of the variance respectively. Support for hypothesis (3) was convincing.

Reciprocal effects model findings

Because feedback effects aggravate multicollinearitv the D_{max} coefficients in Table 4 are high — 0.743 and 0.604 for the second and third equations. Thus, Table 4 results illustrate about every dilemma associated with the multicollinearity problem. The two-stage least squares (2SLS) *t*-values indicate unacceptably high standard errors. One 2SLS path ($p_{12,10}$) has the wrong sign, and several 2SLS estimates are seriously inflated (e.g., $p_{11,12}$ and $p_{12,11}$).[4] When variance inflation is reduced,

TABLE 2

Means, Standard Deviations, and Zero-Order Correlations for Variables in the Literacy and Numeracy Models ($n=94$)

Variables[a]	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	$\overline{X}$	SD
X_1 CS1	1.0000												19.342	9.481
X_2 CS2	.8122	1.0000											21.786	10.097
X_3 CS3	—.2101	—.1818	1.0000										35.797	18.889
X_4 CS4	—.0346	.0532	.5000	1.0000									32.538	13.047
X_5 GP	.9212	.9747	—.2250	.0158	1.0000								—.020	.940
X_6 SS	—.1966	—.1043	.9040	.8189	—.1631	1.0000							—.030	.711
X_7 VOCAB	.3151	.2175	—.5559	—.3588	.2764	—.5533	1.0000						4.690	.928
X_8 LAN	.3289	.2778	—.5369	—.3796	.3208	—.5482	.6693	1.0000					4.735	.909
X_9 WORK	.3033	.2748	—.4799	—.2870	.3082	—.4637	.6553	.6590	1.0000				4.563	.806
X_{10} SKILL	.3571	.2807	—.6008	—.3926	.3351	—.5988	.9277	.8612	.8335	1.0000			.028	1.197
X_{11} READ	.2891	.2072	—.5542	—.3469	.2598	—.5445	.7297	.6335	.7811	.8059	1.0000		4.547	.932
X_{12} MATH	.3514	.3215	—.5159	—.3882	.3575	—.5379	.5705	.6131	.7167	.6972	.6154	1.0000	4.439	.683

[a] Variable identifications: X_1=proportion of miscues lacking graphic similarity, X_2=proportion of miscues lacking phonetic similarity, X_3=proportion of unacceptable semantic miscues, X_4=proportion of unacceptable syntactic miscues, X_5=grapho-phonic cueing strategy deficiency, X_6=syntactic-semantic cueing strategy deficiency, X_7= vocabulary, X_8=language skills, X_9=work study skills, X_{10}=basic skills, X_{11}=reading comprehension, X_{12}=mathematics achievement.

TABLE 3

Path Coefficients and t-values for the OLS and Normalization Regression Estimates of the Covariation between Literacy and Numeracy

Independent Variables	*Dependent Variables*					
	X_{10} SKILL		*X_{11} READ*		*X_{12} MATH*	
	β	*t*	*β*	*t*	*β*	*t*
X_5 GP	.249	3.116	.018	0.319	.154	2.360
	(.250)	3.107	(—.008)	—0.125	(.152)	2.052
X_6 SS	—.555	—6.959	—.142	—2.271	—.208	—2.293
	(—.560)	—6.954	(—.099)	—1.290	(—.194)	—2.229
X_{10} SKILL			.644	10.010	.489	6.684
			(.750)	9.323	(.552)	6.041
R^2	.4079		.5531		.4853	
	(.4146)		(.6556)		(.5556)	
Residual	.769		.668		.717	
	(.765)		(.587)		(.667)	
k_N	.009		.110		.110	
D_{max}	.012		.392		.392	

NOTE: The OLS regression estimates are in parentheses below the normalization regression estimates. The correlation between the residuals (e_4 and e_5) is:

$r_{e_4,e_5} = r_{11,12\cdot5,6,10} = (R^2_{12\cdot5,6,10,11} — R^2_{12\cdot5,6,10} / 1 — R^2_{12\cdot5,6,10})^{1/2}$

$= .031$ (normalization regression analysis result)

$= .069$ (OLS regression analysis result)

t — values greater than 2.0 are significant at the $p \leqslant .05$.

however, by the normalization procedure support for several hypotheses is forthcoming.

First, the basic skills mediate much of the effects of cueing strategies on reading and numeration outcomes. Second, the reading-numeration relationship is reciprocal, and the magnitude of the feedback parameters indicate little support for a traditional hypothesis in which the impact of mathematics on reading is predicted to be of modest proportions compared to the impact of reading on mathematics.

Indirect effects analysis

The pathways of the reciprocal effects model (Figure 2) have been traced from effects back to causes in Table 5. The total causal effect (TCE) of X_4 on X_{11} is —0.155 — about the same as that of X_4 on X_{12} (—0.166) — indicating that the higher the proportion of unacceptable syntactic miscues the lower the performances in both reading and numeration. In sum, hypothesis (2) is supported; namely, that numeration

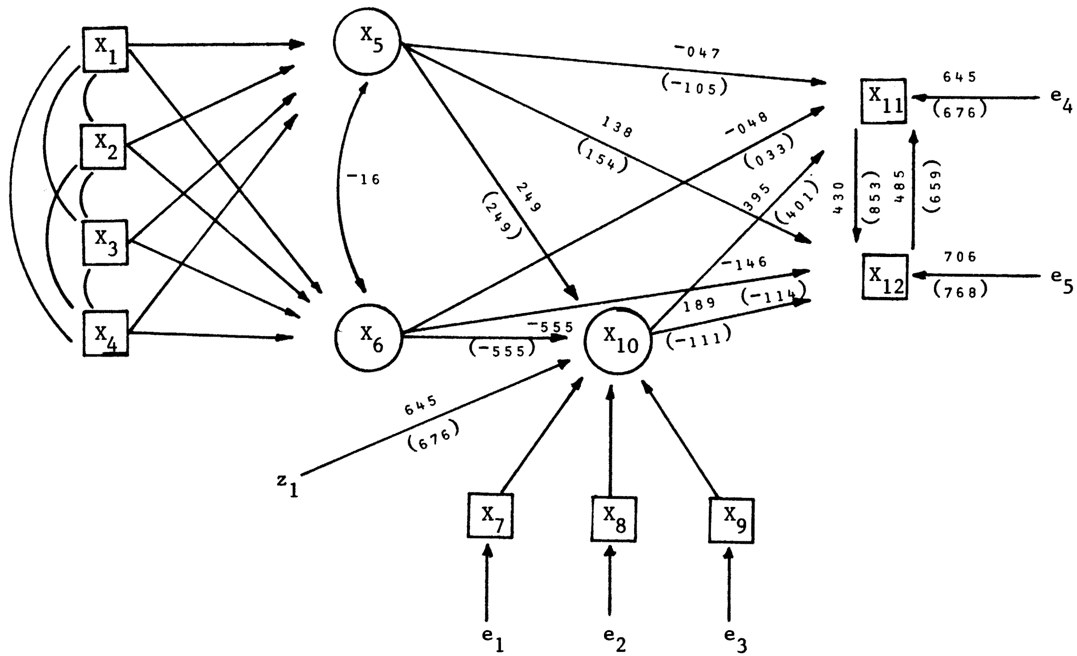

Figure 2

Structure of the Reciprocal Effects Model

Note: Variable Identifications: X_1=proportion of miscues lacking graphic similarity, X_2=proportion of miscues lacking phonetic similarity, X_3=proportion of unacceptable semantic miscues, X_4=proportion of unacceptable syntactic miscues, X_5=grapho-phonic cueing strategy deficiency, X_6=syntactic-semantic cueing strategy, deficiency, X_7= vocabulary, X_8=language skills, X_9=work study skills, X_{10}= basic skills, X_{11}=reading comprehension, X_{12}= mathematics achievement. The structure of the outer relationships is the same as that in Figure 1. The 2SLS estimates are in parentheses below the 2SNR estimates. Decimal points have been omitted.

TABLE 4

Reciprocal Effects Model Results: Path Coefficients and t-ratios from Two-Stage Normalization Regression (2SNR) and Two-Stage Least Squares (2SLS) Analyses

Independent Variables	Dependent Variables					
	X_{10} SKILL		X_{11} READ		X_{12} MATH	
	β	t	β	t	β	t
X_5 GP	.249	3.116	—.047	—0.696	(.138)	1.918
	(.250)	3.107	(—.105)	—1.096	(.154)	1.590
X_6 SS	—.555	—6.959	—.048	—0.647	—.146	—1.839
	(—.560)	—6.954	(.033)	0.286	(—.114)	—0.950
X_{10} SKILL			.395	5.271	.189	2.522
			(.401)	2.091	(—.111)	—0.344
X_{11} READ					.430	4.877
					(.853)	2.145
X_{12} MATH			.485	5.016		
			(.659)	2.164		
R^2	.4079		.5839		.5014	
	(.4146)		(.5434)		(.4094)	
Residual	.769		.645		.706	
	(.765)		(.676)		(.768)	
k_N	.009		.152		.149	
D_{max}	.012		.743		.604	

NOTE: The 2SLS estimates are in parentheses below the 2SNR estimates. t — ratios greater than 2.0 are significant at the $p \leqslant .05$.

and reading performances are more dependent on syntactic and semantic strategies than on the graphic and phonic.

When the TCEs of the predictors of reading are rank ordered it can be seen that the basic skills and numeration performance have the greatest impact (with TCEs of 0.487 and 0.485 respectively). The TCEs for the set of syntactic-semantic strategies (X_6, X_4, and X_3) are also highly significant. Reading has the most powerful TCE on numeration (.430) with the impact of basic skills (.359) and the syntactic-semantic strategy (—.345) about equal in importance.

Elasticities analysis

(1) What will happen to reading performance if mathematics performance changes? or, (2) What will happen to basic skills performances on the basis of a change in a child's syntactic-semantic cueing strategy?

TABLE 5

Total Causal Effects of Predictor Variables in the Reciprocal Effects Model (2SNR Analysis Results)

Independent Variables	*Dependent Variables*	*TIE through Intervening Variables*	*Direct Effects*	*Total Causal Effects (TCEs)*
X_1 CS1	X_5	—	.361	.361
	X_6	—	—.071	—.071
	X_{10}	.129	—	.129
	X_{11}	.049	—	.049
	X_{12}	.107	—	.107
X_2 CS2	X_5	—	.629	.629
	X_6	—	.049	.049
	X_{10}	.129	—	.129
	X_{11}	.031	—	.031
	X_{12}	.111	—	.111
X_3CS3	X_5	—	—.028	—.028
	X_6	—	.470	.470
	X_{10}	—.268	—	—.268
	X_{11}	—.152	—	—.152
	X_{12}	—.169	—	—.169
X_4 CS4	X_5	—	.011	.011
	X_6	—	.491	.491
	X_{10}	—.270	—	—.270
	X_{11}	—.155	—	—.155
	X_{12}	—.166	—	—.166
X_5 GP	X_{10}	—	.249	.249
	X_{11}	.121	—.047	.074
	X_{12}	.089	.138	.227
X_6 SS	X_{10}	—	—.555	—.555
	X_{11}	—.270	—.048	—.318
	X_{12}	—.199	—.146	—.345
X_{10} SKILL	X_{11}	.092	.395	.487
	X_{12}	.170	.189	.359
X_{11} READ	X_{11}	—	.430	.430
X_{12} MATH	X_{12}	—	.485	.485

Such questions are seldom posed by educational researchers, but are commonplace in economics, dating back to Alfred Marshall's research (1890) on the elasticity of demand. In general, elasticity refers to a measure of the degree of responsiveness of a dependent variable to changes in an independent variable.

Consider the mathematics elasticity of reading (question one) which refers to the responsiveness of reading, as the dependent variable, to changes in mathematical performances — the independent variable. From Table 6b it can be seen to be 0.6465; and we can say, therefore, that about the means of the variables (that is, for typical Grade 4 students) a 10% increase in mathematics achievement causes a 6% increase in reading performance. In the case of question two it can be seen (Table 6a) that with reference to the syntactic-semantic elasticity of the basic skills, school-dependent skills are of unit elasticity; that is, there is a one-to-one relationship ($E_j = 1.005$) such that a 10 percent decline in the syntactic-semantic cueing strategy deficiency causes a 10 percent improvement in basic skills performance.

The utility of an elasticities analysis stems from the fact that the elasticities are unit free; that is, their values are independent of the metric of the variables. Thus, in general, large elasticities (greater than 1.0) imply that the dependent variable is very responsive to change in the independent variable.

In terms of the conventional pedagogical wisdom the elasticities results are disappointing. In Table 6b the only large E_j is for MATH; that is, reading comprehension is responsive to changes in numeration but, effectively, to nothing else. Taken literally, a 100% improvement in the basic skills would have virtually no effect (less than 1%) on reading performance, which suggests that for typical Grade 4 pupils all the efforts of the teacher with regard to teaching the basic skills may have much less effect than realized as far as reading is concerned. This is not to say that teaching the basic skills may not have worthwhile effects on anything else or that they are not intrinsically worthwhile. Similarly, numeration performance (Table 6c) is responsive to changes in reading comprehension but not to changes in other predictors.[5]

CONCLUSION

If we assume that the literacy-numeracy models are adequately specified, there is substantial support for three of the four hypotheses. First, the covariance model results demonstrate that most of the covariation between literacy and numeracy was attributable to grapho-phonic and syntactic-semantic cueing strategies, along with the basic skills. Second, the indirect effects analyses (Table 5) supported the hypothesis that the syntactic-semantic cueing strategy would have greater impact on literacy and numeracy than the grapho-phonic strategy. Third, the reading-

TABLE 6

Elasticities Analysis Results for Two-Stage Normalization Regression Analysis of the Reciprocal Effects Model[a]

Table 6a.
Normalization Regression Equation No. 1: X_{10}(SKILL) = f(X_5, X_6)

Indep. Variables	$\bar{X}_j$	*Coefficients* (β_j)	*Elasticities* (E_j)
X_5 GP	—.020	.3090	—.2245
X_6 SS	—.030	—.9333	1.0005

$\bar{Y} = \bar{X}_{10}$ (SKILL) = .028; K_N = .009

Table 6b. 2SNR Equation No. 2: X_{11}(READ) = f(X_5, X_6, X_{10}, X_{12})

Indep. Variables	$\bar{X}_j$	β_j	E_j
X_5	—.020	—.4628	.0002
X_6	—.030	—.6228	.0004
X_{10}	.028	3.0717	.0019
X_{12}	44.386	.6623	.6465

$\bar{Y} = \bar{X}_{11}$ (READ) = 45.470; k_N = .152

Table 6c. 2SNR Equation No. 3: X_{12} (MATH) = f(X_5, X_6, X_{10}, X_{11})

Indep. Variables	$\bar{X}_j$	β_j	E_j
X_5 GP	—.020	1.0041	—.0005
X_6 SS	—.030	—1.4072	.0009
X_{10} (SKILL)	.028	1.0766	.0007
X_{11} (READ)	45.470	.3149	.3226

$\bar{Y} = \bar{X}_{12}$ (MATH) = 44.39; K_N = .149

[a]Where $E_j = \beta_j$ (X_j/Y). Interpretation: If E_j = 1.0005 (Table 6a) we say that about the mean of the variables a 1% increase in X_6(SS) will lead to a 1% increase in Y(X_{10}—SKILL)

numeration model was reciprocal such that both outcomes were approximately equal in their feedback effects on the other. Collectively, then, the findings support the "new" theory and hence promote rejection of the primacy of reading hypothesis. Fourth, since the theory was based on the notion that analysis-by-synthesis decoding processing was common to speech recognition, arithmetic problem solving, and reading comprehension, and since the decoding of speech is developmentally prior to the other two, there was prima facie support for the thesis that the origins of both literacy and numeracy are to be found in the logic of speech perception.

Support for the first hypothesis, however, was equivocal; that is, that the basic skills will mediate the effects of intuitive linguistic rule-following strategies as predictors of reading and numeration. Support for the hypothesis was forthcoming in three instances; the covariance model results (Figure 1), the reciprocal effects model results (Figure 2), and the indirect effects analysis (Table 5). But these findings were not confirmed by the elasticities analysis. Thus, paradoxically, although the basic skills mediated the effects of the cueing strategies, this cannot be interpreted to mean that the reading and numeration outcomes were responsive to these predictors, which "proved" to be inelastic. We do not know why, and we caution the reader to exercise a healthy scepticism in so far as the elasticities results are concerned. Nevertheless, these results showed that about their means, the reading and numeracy variables were only responsive to each other, not to the source variables or to the basic skills.

In retrospect we tentatively make the following suggestion regarding hypothesis number one. On the basis of the models estimated in the study we can only infer that the reader or problem solver is on the inside of the logic of analysis-by-synthesis decoding by noting the pupil's proficiency in employing the cueing strategies. The processes themselves — hypothesizing, predicting, inferencing, and others — are not amenable to direct observation. In this sense, the cueing strategies are proxies or surrogate variables which stand for the processes — but which ones, and to what effect, we do not know. It may be that the proxies in the formulated model are inadequate. (At this early stage of model estimation in reading this is hardly surprising.) It is what they stand for that is all important, and as yet our models of the processes are not equal to the task. This is not to say that we are back to where we started. It must be clear that model building is an incremental process. Not only has research to be replicated, but models have to be extended and elaborated.

We need more experimental research in cognitive processing. A primary principle of the theory tested in this paper was that the logical roots of numeration and reading performances lie in the analysis-by-synthesis model of speech recognition. One viable research route might be to try to disaggregate the cueing strategies further — say, by incorporating the logical connectives and information units that children use in their retelling discourse. Fagan's (1978) recent work is at the cutting edge of this route, though as yet formal models integrating miscue analysis and discourse analysis have not been estimated. Aural recognition analysis, though undeveloped, would also seem to be a viable route for the reading researcher, since according to the primacy of the speech recognition hypothesis developed in this paper, aural recognition precedes both numeration and reading.

A final paradox. Why is grapho-phonic deficiency a good predictor of both basic skills and numeration? Note the positive TCEs (.249 and .227) for variable X_5 in Table 5. It seems that those Grade 4 pupils who are successfully making the transition from learning to read to reading to learn take grapho-phonic skills for granted. These meaning seekers overlook grapho-phonic miscues (that is, regard them as expendable) if they do not detract from the flow of meaning. It seems as if reading for meaning is almost at the expense of grapho-phonic accuracy and perfection. Obversely, grapho-phonic perfection in sounding out words is all too often (as Goodman, 1967, was the first to point out) at the expense of comprehension.

NOTES

The research reported in this paper was supported by grants from the Faculty of Education, Memorial University of Newfoundland, and Grant No. S86-786 from the Social Sciences and Humanities Research Council of Canada. W. F. Lee, Memorial University, was the Research Associate for the methodological research and primarily responsible for the formulation of the statistical theory underlying Normalization Regression Analysis. The Research Consultant was W. S. Luk, Simon Fraser University. The authors gratefully acknowledge their assistance.

1 To avoid unnecessary confusion, it is pointed out that for stylistic reasons the common language terms "literacy" and "reading" or "reading comprehension" are used interchangeably throughout the paper, as are the terms "numeracy," "numeration," "arithmetical problem solving," and "verbal arithmetic problem solving," and the terms "speech perception" and "speech recognition."

2 The problem is one that would prove too difficult for most elementary school children; hence, is not typical of the verbal arithmetic problems that (say) 10-year-olds are expected to solve. It was chosen because it exemplifies the elements of the analysis-by-synthesis procedure, especially of the necessity of invoking syntactic and semantic rules, whether these are related to language symbols or numerical symbols. Selection of a slightly more complex numerical problem helps to bring out more readily the principles of problem solving that are common to both speech perception and reading comprehension.

3 The algebraic statements give equations of the form:

$x_1 = 2 * (0.2 * x_2)^2$

$x_2 = 20$

$? = x_1$

and solving for x_1 gives:

$x_1 = 2 * (0.2 * x_2)^2$; since $x_2 = 20$, then

$x_1 = 2 * (0.2 * 20)^2 = 32$

4 A word of explanation. Ill-conditioned or highly collinear data sets have linear vectors which depart from the condition of independency or orthogonality. In these circumstances OLS regression estimates will be inflated. This is because the data matrices will have high variance and covariance; as a result, the subsequent struc-

tural estimates (the βs) will be highly correlated. Because of the independency of the estimates, if one is erroneous, the other will be; for example, when two predictors are highly positively correlated the estimated coefficients will be highly negatively correlated. This means that if one coefficient is overestimated, the other will be underestimated. It is this high correlation between the estimates which accounts for the excessively large sum of squares ($\beta'\beta$) in the OLS solutions, and why it is not uncommon for the estimates to have the wrong sign. Thus, in Table 3 (or see Figure 1) $p_{11,10}$ is overestimated, while $p_{11,6}$ is underestimated; and in Figure 2 $p_{12,11}$ and $p_{11,12}$ are overestimated, while $p_{12,10}$ is underestimated and has the wrong sign.

[5] One could inquire as to the elasticities of the predictors in a recursive reading model; that is, one with variables X_5, X_6, and X_{10} as predictors, and X_{11} as the dependent variable. They are: —0.0001, .0012, and .0031 respectively. For a model of arithmetic problem solving the news is equally gloomy; the elasticities for X_5, X_6, and X_{10} on X_{12} are: —0.0005, .0014, and .0017.

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