The Alberta Journal of Educational Research *Vol. XLV, No. 4, Winter 1999, 428-447*

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Theory-Based Prediction of Early Reading

This article presents a theory of the cognitive processes involved in learning to read and examines the degree to which measures derived from this theory are able to predict success in reading. Measures were selected to address five phonological processing constructs (naming speed, memory, rhyming, phonological synthesis, and phonological analysis), letter knowledge, and the ability to pronounce words by analyzing them into smaller parts (decoding). Measures of these constructs and several measures of reading achievement were administered to an initial sample of 161 kindergarten children and then readministered to as many of the same children as possible in grades 1 and 2; in grade 3 the reading achievement tests were administered. Principal components analyses were used to derive factor scores for the phonological constructs in kindergarten and grades 1 and 2. In grade 2 five factors were found, but in kindergarten and grade 1 the phonological synthesis and analysis measures formed one phonological awareness factor. The factor scores, letter knowledge, decoding, and the reading achievement scores for each grade were used as predictors of reading achievement in subsequent grades in a series of hierarchical regression analyses. Results supported the proposed theory, with phonological awareness (or analysis), naming speed, and letter recognition being the most frequent significant predictors and R^2s ranging from .69 to .89. The constructs identified in the theory are argued to be important targets for both assessment and instruction. The value of theoretical models of achievement is discussed.

Cet article présente une théorie sur les processus cognitifs impliqués dans l'apprentissage de la lecture et étudie à quel point les mesures qui en découlent peuvent prédire le succès dans la lecture. Les mesures ont été sélectionnées pour refléter cinq éléments de traitement phonologique (vitesse de dénomination, mémoire, rime, synthèse phonologique et analyse phonologique), la connaissance des graphèmes et la capacité de prononcer les mots en les découpant en plus petites unités (décodage). On a mesuré ces cinq éléments et, à plusieurs reprises, le rendement en lecture d'un échantillon initial de 161 enfants à la maternelle. Plus tard, on a refait l'analyse avec autant de ces enfants que possible alors qu'ils étaient en première et deuxième années. Quand ils sont arrivés en troisième année, on a administré des tests de rendement en lecture. Des analyses de composantes principales ont servi dans la dérivation des scores factoriels pour les éléments phonologiques à la maternelle et dans les deux premières années. Chez les enfants en deuxième année, on a retrouvé cinq facteurs, mais chez ceux à la maternelle et en première année, les mesures de synthèse et d'analyse phonologiques constituaient un facteur de reconnaissance phonologique. Les scores factoriels, la connaissance des graphèmes, le décodage et les résultats des tests de rendement en lecture pour chaque niveau scolaire ont servi de valeurs prédictives du rendement en lecture dans les années scolaires subséquentes pour une série d'analyses de régression hiérarchicales. Les résultats appuient la théorie proposée, les valeurs prédictives les plus significatives étant la reconnaissance (ou l'analyse) phonologique et la connaissance des graphèmes. Les R^2 va-

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riaient entre 0,69 et 0,89. Il est proposé que les éléments identifiés par la théorie représentent des cibles importants tant pour l'évaluation que pour l'enseignement. On discute de la valeur des modèles théoriques de rendement.

One of the first lessons to be learned by someone setting out to study mental phenomena is the distinction between constructs (the mental phenomena) and their indicators (our measures of them). Indicators are imperfect measures of constructs, and overemphasis on them may warp the conclusions one draws. Many concerns have been raised about this issue in education. For example, it has been said that the goals of the curriculum are too complex for student achievement to be assessed adequately by standardized tests and that specific achievement tests may focus more on what is easy to measure than what is central to the goals of the curriculum (Barlow & Robertson, 1994). Furthermore, it has been argued that teachers will change their teaching to meet the apparent targets of assessment. Thus standardized, and therefore presumably simplistic, assessment will drive teachers to focus on the trivia of indicators rather than on the more important core of the achievement constructs.

On the other hand, there is widespread consensus, at least among policy makers and consumers, that assessment is needed to monitor progress and encourage improvement (Nikiforuk, 1994). The solution to this conundrum is to construct better theories of what achievement is and thereby develop more appropriate models of the links between indicators and constructs. We argue that pessimism about the consequences of standardized assessment has stemmed from undue focus on large and ill-defined constructs such as intelligence and self-concept, for which no clear theories and therefore no clear indicators exist.

Early reading ability provides a worthwhile case in point. If early reading is portrayed as complex, attempts to employ straightforward measures will be opposed, as will attempts to apply the findings from such measurement to instruction. The purpose of this article is to present a cognitive theory of learning to read, provide examples of how the theoretical constructs can be measured, and demonstrate how effective these measures are as predictors of reading achievement.

The Theoretical Basis for Learning to Read

Two broadly distinct theoretical views exist regarding how children learn to read. The analytic view, which attempts to identify the component skills of reading and the oral language and other skills that contribute to reading, and the holistic view, which maintains that reading is too complex and its components too interdependent for analysis of component skills to be profitable. To a large extent the basis for this distinction is philosophical, derived from individuals' fundamental world views. The analytic view is essentially a scientific one, the holistic view more romantic (Stanovich, 1994). The analytic view has been associated with the teaching of phonics and grammar, and the focus has been on the automatization of basic skills to allow attention to be devoted to higher-level activities (Adams, 1990). The holistic view has been associated with the whole language approach to reading (Goodman & Goodman, 1979; Smith, 1971), in which reading is seen as a natural activity (like oral language) and the focus is on meaning and enjoyment. It has also been associated with the whole word approach to learning to read, in which the child is intended to learn to recognize words as whole units. Instead of dealing with words as whole units, learners are encouraged to break words down into sublexical parts. Over the last 30 years there have been numerous comparisons of programs representing the two orientations. The evidence has been overwhelmingly on the side of the analytic approach (Adams, 1990; Chall, 1967, 1979, 1982; Symons, Woloshyn, & Pressley, 1994). However, the whole language approach has been influential in many jurisdictions ranging from New Zealand to Ontario (Adams, 1990).

One consequence of the holistic approach has been a suspicion of measurement and objective assessment. Reading is so complex, the argument goes, that no objective measure could capture it fully. Furthermore, it has been argued, teachers are influenced by assessment: simplistic tests will drive teachers to simplistic teaching (Barlow & Robertson, 1994). Even if this argument were valid it would be pernicious, because in the absence of any measurement the only basis for deciding whether progress is being made (by either the individual child or the system) is intuition. Without measurement there can be no assessment of progress, and without assessment there is no guidance for practice. Policy-makers and consumers have expressed the suspicion, difficult to test, that these views have led to lower reading competence (Nikiforuk, 1994).

On the other hand, there is some reason to be suspicious of reading measures. Little theory seems to have gone into the design of such measures beyond the commonsense notions that reading may be divided into word recognition and comprehension, and the latter into literal and inferential comprehension. Measures of reading comprehension, for instance, have been criticized for measuring neither reading nor comprehension (not reading, because you can do quite well on some measures without reading the text, and not comprehension, because the measures often only require only the location of information or memory for information).

What has been missing until recently is a solid theoretical basis for what to measure, when to measure it, and what to regard as the critical outcomes. Recent research has focused on the importance of three factors in learning to read: oral language phonological processing, letter knowledge, and knowledge of how to pronounce words by analyzing them into smaller components (Adams, 1990; Bradley & Bryant, 1985; Elbro, Borstrøm, & Petersen, 1998; Ellis & Large, 1988; Wagner, Torgesen, & Rashotte, 1994). Phonological processing refers to the cognitive mechanisms by which we encode, manipulate, and generate the sound structure of spoken words. Phonological measures administered to children as young as 36 months predict their later reading skills (Maclean, Bryant & Bradley, 1987); when administered to older children, they are generally excellent predictors of concurrent and later reading achievement over the learning-to-read years (ages 5-8, or grades K-3) (Adams, 1990; Torgesen, Wagner, & Rashotte, 1994; Wagner, Torgesen, Laughon, Simmons, & Rashotte, 1993; Wagner et al., 1994). Recent work has begun to put theoretical order on what had been a relatively disorganized collection of phonological measures and constructs (Kirby, Beggs, & Martinussen, 1995; Wagner, et al., 1994). Our current best sense of phonological development and its contribution to learning to read is shown on the left-hand side of Figure 1. The five

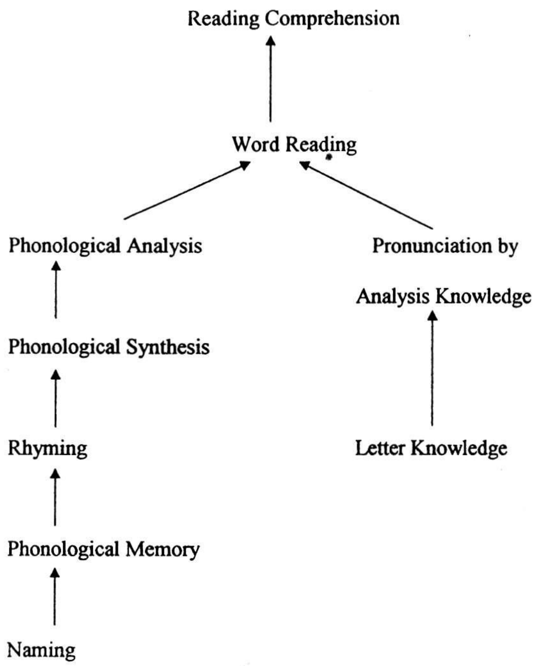

Figure 1. Schematic diagram illustrating the development of phonological processing, letter knowledge, knowledge of pronunciation by analysis, and their contribution to learning to read.

phonological constructs listed have appeared in many of the studies referred to above. Less certain is their sequence and the causal relations among them. The sequence shown was suggested by Kirby et al. (1995) and has been supported by several thesis studies using structural equation modeling (Beggs, 1996; James, 1996).

The earliest of the phonological constructs to appear developmentally is Naming, which indicates the ability to name presented objects. As Naming develops, it becomes faster or more efficient. Efficient Naming contributes to Phonological Memory, whereby ordered sets of sounds can be retained and repeated. Both of these skills appear in the second year of life and continue to develop and improve; they also provide the basis for the later-developing phonological skills. The next ability to appear is Rhyming, which is demonstrated by the ability to recognize or produce rhyming words; it also represents the first skill in which the child must deal with units smaller than the individual word. Phonological Synthesis requires the child to produce a word from individual sounds, and Phonological Analysis requires the breaking down of a presented word into component sounds for subsequent manipulation. In measures of the latter two abilities, sometimes jointly labeled *phonological awareness*, the sounds involved may be syllables, onsets and rimes, or phonemes. Onsets and rimes are the components of syllables, the onset being the consonant or consonant cluster at the beginning and the rime being the vowel and any following consonants. In Figure 1 these five abilities are shown in developmental order; we expect, however, that later-developing abilities contribute to the improvement of earlier-appearing abilities (reciprocal causation). It is also possible that several of these factors, especially the two phonological awareness factors, do not become distinct from each other until well into the learning-to-read period.

The other two key contributors to early reading are shown on the right of Figure 1. Letter knowledge involves first the knowledge of letter names, then their recognition as printed characters, and finally the sounds they make as individuals and as groups. Letter knowledge then contributes to the learning of word decoding whereby presented words are sounded out to aid in identification. Although these connections are not shown in Figure 1, the earlier phonological abilities facilitate the acquisition of letter knowledge and decoding, which in turn facilitate the further development of phonological processing abilities.

Each of the components identified in Figure 1 has been studied extensively. The details of their operationalization in the present study are presented below. These measures are used in this study to demonstrate how the constructs of a comprehensive theory of learning to read can be measured and how effective these measures are as predictors of reading achievement, to illustrate the value of a well-developed theory for educational assessment.

Method

Participants

In the first year of the study, 161 children in senior kindergarten (mean age 66.7 months) were recruited to participate (senior kindergarten is the first year of compulsory schooling in Ontario). Letters describing the study were sent to parents of all children in the targeted classes. All participating schools were in Kingston, Ontario, and served a broad range of social class neighborhoods. In grade 1, 121 of these children were tested again, together with 42 new participants. In grade 2 105 of the original participants were tested for the third time, together with 37 participants who continued from grade 1. No new participants were added in grade 2. In grade 3, 95 of the original participants were administered a subset of the original tests, including all reading tests (see below). Attrition was due to children either moving out of the area, being unavailable for testing, or parents withdrawing their child's participation. Comparisons between the children who remained in the study and those who left indicated no significant differences between the groups. Therefore, it seems reasonable to assume that attrition was random and did not result in a biased sample at the later stages of the project.

Tasks

Phonological Analysis

Participants' phonological analysis skills were assessed with two tasks taken from Wagner et al. (1993). Sound Isolation (SI) required the participant to identify the first, the last, or the middle sound in a word. There were six practice items and 15 test items consisting of three- and four-phoneme one- or two-syllable words. Phoneme Elision (PE) required the participant to repeat a word after deleting an identified phoneme. The specific instructions were as follows: "Say the word /cat/. Now say the word /cat/ without the /k/." All phonemes to be deleted were consonants, the position of which varied. After deleting the target phoneme, the remaining phonemes formed a word (e.g., /seed/ without the /d/ leaves /see/). There were six practice items and 15 test items consisting of three- to five-phoneme one- or two-syllable words. Both tasks were discontinued after four mistakes in the last seven items. A participant's score was the number of correct items.

Phonological Synthesis

The two phonological synthesis tasks were taken from those used by Wagner et al. (1993). In each item of Blending Onset (BO) and Rhyme the participant is orally presented the onset (the initial consonant or consonant cluster) and rime (the remaining vowels and consonants) of a word at the rate of two per second and then asked to pronounce the word that resulted when the onset and rime are blended together (e.g., "What word does /b/ - /ig/ say?"). The task consisted of six practice items and 15 test items. The second blending task, Blending Phonemes (BP), is otherwise similar but now the participant hears and blends individual phonemes into words (e.g., "What word does /m/ - /oo/ - /n/ say?"). The first item consisted of two phonemes, whereas the most difficult items had six phonemes. Both tests were discontinued after four mistakes in the last seven items.

Rhyming

The two rhyming tasks were adapted from Maclean et al. (1987). Rhyme Production (RP) required the child to report a word that rhymed with the one presented by the experimenter (e.g., "Say a word that rhymes with tail"). Both real words and nonsense words were accepted as correct responses. The task included five practice items and five test items in kindergarten and 15 test items in grades 1 and 2. Presentation was discontinued after four errors in the last seven items. Nursery rhyme knowledge (NR) required the child to recite four common nursery rhymes: "Humpty Dumpty," "Hickory Dickory Dock," "Baa Baa Black Sheep," and "Jack and Jill." The child was given a score of 0 (no knowledge), 1 (at least one complete line), or 2 (a complete recital).

Naming

Two naming tasks were administered to assess rapid phonological code retrieval. The Color naming (CN) task required the participant to state as quickly as possible the names of four colors (blue, green, red, and yellow). The colors were presented in 4 x 4 arrays in random order. Before beginning the timed naming, each participant was asked to name the colors to ensure that the colors were familiar. The total time in seconds to name 32 targets was the score. Picture naming (PN) was otherwise similar to CN but now the targets were outline drawings of four common animals (bird, horse, pig, and cat).

Phonological Memory

Both phonological memory tests were adapted from the Das-Naglieri Cognitive Assessment System (Das & Naglieri, 1997) in which they are used to measure successive processing, but due to their verbal nature are also suitable for assessing phonological memory. Sentence repetition (SR) requires the participant to repeat sentences that use color words in place of nouns and verbs. For example, item 1 is "The white is blue," whereas Item 10 is "The green reds the blue and yellows the brown." Each item is scored pass only when it is repeated completely accurately. Presentation is discontinued after four consecutive failures and the participant's SR score was the number of sentences passed. Word series (WS) is a word memory span test in which the participant is asked to repeat a series of words in the order they are presented (e.g., shoe, dog, man, book). Words are presented orally at a rate of one per second. The first two series consist of only two words, and the length of series is gradually increased so that the most difficult items consist of nine words. Only nine single-syllable words are used as targets. Presentation of items is discontinued after four consecutive failures. The participants' WS score was the number of series correctly reproduced.

Letter Knowledge and Reading Tasks

Participants' letter knowledge was assessed by administering a Letter recognition test (Clay, 1993). This simple test asks the participant to identify each of the uppercase and lowercase letters. Two lowercase letters, a and g, are presented in two different fonts, so the total possible score is 54.

Reading performance was assessed in all grade levels using tests from the Woodcock Reading Mastery Tests-Revised battery (Woodcock, 1987). Form G tests were used in kindergarten and grade 2, Form H in grades 1 and 3. The Word attack test was used to measure participants' ability to apply phonic and structural analysis skills to pronouncing nonsense or low-frequency words that are not recognizable by sight. Stimulus words in this test consist of simple consonant-vowel combinations (e.g., "dee," "apt," "ift"). The Word identification test requires the participant to read isolated—and at this level also high frequency—words aloud (e.g., "is," "you," "and"). The Passage Comprehension test requires the participant to read a short passage (usually two to three lines) and identify a key word missing from the passage (e.g., "Martha's painting is dry. She ____ it yesterday").

Procedure

Each of the tests described above was administered in kindergarten and grades 1 and 2 (with the exception that the Passage comprehension test was not administered in kindergarten). The three Woodcock subtests were also administered in grade 3. All participants were tested individually in their respective schools during school hours by trained experimenters. Testing was divided into four sessions, each lasting roughly 20 to 30 minutes.

Results

The results are presented in two sections. The first addresses the structure of the phonological processing domain at the kindergarten, grade 1, and grade 2 levels, and the second presents regression analyses predicting the grade 1, 2, and 3 Word Identification and Passage Comprehension scores.

Structure of Phonological Processing

Principal component factor analyses with Varimax rotation were performed with kindergarten, grade 1, and grade 2 data separately to examine the underlying factor structure of the 10 phonological tasks.

Table 1 displays the correlations among the 10 phonological measures in kindergarten. In kindergarten the initial principal components solution showed three factors with eigenvalues larger than 1. In this three-factor solution, the first factor included analysis and synthesis tasks together with Rhyme Production (RP). The second factor included naming tasks and Nursery Rhyme

Table 1

Correlations Among the 10 Phonological Variables in Kindergarten (n=161)

Variable		*1.*	*2.*	*3.*	*4.*	*5.*	*6.*	*7.*	*8.*	*9.*	*10.*
	Mean	3.07	4.05	6.47	5.89	5.29	3.12	39.68	42.37	5.14	9.49
	SD	3.95	4.51	5.69	5.25	2.59	2.03	12.47	11.53	2.29	2.99
1. Phoneme elision											
2. Sound isolation		.657	—								
3. Blending onset and rime		.568	.674	—							
4. Blending phonemes		.596	.698	.853	—						
5. Nursery rhymes		.198	.266	.288	.243	—					
6. Rhyme production		.370	.416	.421	.468	.374	—				
7. Color naming		−.397	−.328	−.320	−.289	−.336	−.301	—			
8. Picture naming		−.336	−.381	−.327	−.321	−.297	−.297	.683	—		
9. Sentence repetition		.393	.309	.399	.354	.132	.259	−.210	−.261	—	
10. Word series		.375	.342	.355	.297	.189	.292	−.249	−.273	.626	—

Table 2
Rotated Component Matrix for Four-Factor Solution in Kindergarten

	Factor			
Variable	*1*	*2*	*3*	*4*
1. Phoneme elision	.720	−.274	.262	.002
2. Sound isolation	.819	−.206	.131	.144
3. Blending onset and rime	.848	−.103	.190	.200
4. Blending phonemes	.894	−.008	.122	.185
5. Nursery rhymes	.007	−.219	.004	.869
6. Rhyme production	.393	−.008	.168	.663
7. Color naming	−.183	.878	−.009	−.178
8. Picture naming	−.201	.864	−.137	−.135
9. Sentence repetition	.239	−.009	.863	.004
10. Word series	.173	−.130	.865	.139

Note. Extraction method: Principal component analysis; rotation method: Varimax with Kaiser normalization.

Knowledge (NR). The third factor consisted of the two phonological memory tasks. This solution explained 69.3% of the variance, and commonalities were generally large (>.61) with the exception of the two rhyming tasks. The fourth factor had an eigenvalue of .88, and when a four-factor solution was computed the fourth factor included the two rhyming tasks. This solution is displayed in Table 2. The four-factor solution shows clear awareness (analysis and synthesis combined), naming, memory, and rhyming factors and explained 78.1% of the total variance. All commonalities were .63 or larger. The five-factor solution kept this factor structure otherwise intact, but split the two rhyming tasks into their own factors. The four-factor solution was selected for later use, primarily because of its theoretical meaningfulness.

Table 3 displays the correlations among the 10 phonological measures in grade 1. In grade 1 only two factors had eigenvalues larger than 1. Eigenvalues for the third, fourth, and fifth factors were .89, .82, and .60, respectively. In the initial two-factor solution, the first factor included analysis and synthesis tasks and the second rhyming, naming, and memory tasks. This solution explained 60.1% of the variance, and commonalities for all rhyming and memory tasks were smaller than .5. A three-factor solution explained 68.9% of the variance and was similar to the three-factor solution in kindergarten. Commonalities for the rhyming tasks were still low (.50 and .47). The four-factor solution displayed in Table 4 was similar to the four-factor solution in kindergarten and explained 77.2% of the variance. All commonalities were now higher than .65.

The five-factor solution put RP and Sentence Repetition in one factor and left NR and Word Series on factors of their own. The four-factor solution was selected for further use.

Finally, Table 5 displays correlations among the 10 phonological measures in grade 2. In grade 2 three factors had eigenvalues larger than 1. Eigenvalues for the fourth and fifth factors were .67 and .65 respectively. The three-factor solution explained 68.3% of the variance and had analysis and synthesis tasks

Table 3
Correlations Among the 10 Phonological Variables in Grade 1 (n=163)

Variable	*1.*	*2.*	*3.*	*4.*	*5.*	*6.*	*7.*	*8.*	*9.*	*10.*
Mean	5.84	6.87	10.44	9.38	6.06	11.83	32.33	33.81	6.24	10.87
SD	4.83	4.84	4.56	4.32	2.06	4.81	11.18	11.72	2.72	2.82
1. Phoneme elision	—									
2. Sound isolation	.777	—								
3. Blending onset and rime	.569	.570	—							
4. Blending phonemes	.586	.600	.800	—						
5. Nursery rhymes	.338	.393	.357	.287	—					
6. Rhyme production	.423	.485	.376	.318	.481	—				
7. Color naming	–.465	–.497	–.281	–.228	–.338	–.395	—			
8. Picture naming	–.461	–.439	–.235	–.286	–.424	–.393	.673	—		
9. Sentence repetition	.390	.477	.323	.311	.333	.414	–.370	–.370	—	
10. Word series	.241	.326	.131	.143	.230	.209	–.287	–.316	.410	—

Table 4
Rotated Component Matrix for Four-Factor Solution in Grade 1

Variable	*Factor* 1	2	3	4
1. Phoneme elision	.715	–.449	.117	.164
2. Sound isolation	.692	–.398	.202	.291
3. Blending onset and rime	.870	–.002	.245	.004
4. Blending phonemes	.901	–.005	.129	.007
5. Nursery rhymes	.159	–.189	.832	.111
6. Rhyme production	.253	–.233	.744	.149
7. Color naming	–.163	.861	–.172	–.154
8. Picture naming	–.130	.823	–.262	–.169
9. Sentence repetition	.260	–.162	.330	.670
10. Word series	.004	–.164	.003	.894

Note. Extraction method: Principal component analysis; rotation method: Varimax with Kaiser normalization.

on the first factor, naming tasks and RP on the second factor, and memory tasks on the third factor. NR had a split loading on the two latter factors. The four-factor solution split analysis and synthesis to different factors (Phoneme Elision had a high loading on both) and the five-factor solution produced clear analysis, synthesis, rhyming, naming, and memory factors. Table 6 displays the five-factor solution that was selected for further use. This solution explained 81.5% of the variance and all commonalities were .72 or higher.

To summarize, four-factor solutions with separate factors for phonological awareness (analysis and synthesis combined), rhyming, memory, and naming speed fitted the data from kindergarten and grade 1. For the grade 2 data a solution with five factors representing the suggested five phonological constructs was obtained.

Predicting Word Identification and Passage Comprehension

A series of hierarchical linear regression analyses was performed next in order to assess the relative importance of phonological processes in predicting reading performance. Factor scores from the kindergarten and grade 1 four-factor solutions (with analysis and synthesis combined as *awareness*) and from the grade 2 five-factor solution were used as predictors in these analyses, together with the reading scores from previous years (Letter Recognition, Word Identification, Word Attack, and Passage Comprehension).

In every regression analysis, step 1 consisted of entering the autoregressor from the previous year (see below). Following this, all other predictor scores (reading and phonological) from the previous year were entered stepwise (the inclusion criterion was $p<.05$). For the grade 2 analyses, the kindergarten autoregressor was entered (stepwise) after grade 1 predictors, followed by the other kindergarten predictor variables. For grade 3 analyses, the same procedure was replicated with both grade 1 and kindergarten predictor scores in this order. Thus in all analyses autoregressors were entered before other predictor

Table 5
Correlations Among the 10 Phonological Variables in Grade 2 (n=143)

Variable	*1.*	*2.*	*3.*	*4.*	*5.*	*6.*	*7.*	*8.*	*9.*	*10.*
Mean	10.95	9.26	13.85	10.92	5.78	13.43	27.93	31.01	7.40	8.82
SD	3.52	3.69	1.76	2.90	2.13	2.45	7.70	7.59	2.57	2.31
1. Phoneme elision	—									
2. Sound isolation	.616	—								
3. Blending onset and rime	.533	.418	—							
4. Blending phonemes	.628	.470	.639	—						
5. Nursery rhymes	.344	.371	.277	.366	—					
6. Rhyme production	.410	.346	.334	.453	.440	—				
7. Color naming	–.382	–.335	–.276	–.342	–.347	–.402	—			
8. Picture naming	–.361	–.294	–.264	–.408	–.443	–.420	.636	—		
9. Sentence repetition	.459	.393	.355	.468	.454	.432	–.282	–.327	—	
10. Word series	.380	.252	.298	.325	.396	.274	–.186	–.272	.672	—

Table 6
Rotated Component Matrix for Four-Factor Solution in Grade 2

Variable	*Factor* 1	2	3	4	5
1. Phoneme elision	.528	.247	−.217	.607	.010
2. Sound isolation	.229	.115	−.134	.891	.178
3. Blending onset and rime	.859	.150	.010	.163	.008
4. Blending phonemes	.776	.192	−.201	.231	.238
5. Nursery rhymes	−.001	.355	−.239	.273	.682
6. Rhyme production	.332	.009	−.220	.006	.807
7. Color naming	−.144	−.005	.872	−.183	−.133
8. Picture naming	−.152	−.167	.839	−.006	−.245
9. Sentence repetition	.238	.782	−.117	.192	.278
10. Word series	.148	.918	−.010	.007	.008

Note. Extraction method: Principal component analysis; rotation method: Varimax with Kaiser normalization.

variables, and variables closer in time to the dependent variable were entered before variables farther away in time.

The autoregressor was the score on the same measure from the previous year. Due to the low reading levels in kindergarten (Word Identification mean = 5.11 and mode = 0), Letter Recognition was included as a second autoregressor, representing rudimentary literacy skills. Also, because Passage Comprehension was not administered in kindergarten, Word Identification and Letter Recognition were used as autoregressors for grade 1 Passage Comprehension. Entering the autoregressor always first into the prediction model provides a conservative estimate of the importance of the other predictor variables.

Table 7 summarizes the results from the hierarchical linear regression analyses predicting the Word Identification score in grades 1, 2, and 3. Table 7 shows, not surprisingly, that the previous year's Word Identification score accounted for most of the Word Identification variance in each grade level. In essence, this tells the old developmental story: If you want to predict the performance level at time *T* in any task, the best predictor is the performance level on the same task at time *T*-1.

However, even after controlling for the effect of the autoregressor, Word Identification scores were predicted significantly by two or more phonological processing measures from the previous year. Awareness and Naming were the phonological predictors for grades 1 and 2, Analysis (part of Awareness), Naming, and Memory for grade 3. The changes in R^2 were, however, relatively small with the exception of grade 2. Adding grade 1 Awareness and Naming to the model predicting the grade 2 Word Identification score increased the variance accounted for by 14% compared with the model including only the autoregressor.

The previous year's Letter Recognition score was a significant predictor in all analyses. We should note that correlation between Word Identification and

Table 7
Summary of Hierarchical Regression Analyses for Variables Predicting Word Identification in Grades 1, 2, and 3

Variable	R^2	*B*	*SE B*	β
Grade 1				
Step 1	.84			
Word Identification in K		1.12	.05	.82***
Letter Recognition in K		.204	.04	.19***
Step 2	.86			
Word Identification in K		1.04	.06	.76***
Letter Recognition in K		.15	.04	.14**
Awareness in K		2.69	.82	.15**
Step 3	.86			
Word Identification in K		.99	.06	.73***
Letter Recognition in K		.12	.05	.11*
Awareness in K		3.39	.86	.19***
Naming in K		−1.64	.68	−.09*
Grade 2				
Step 1	.53			
Word Identification in grade 1		.76	.07	.73***
Step 2	.63			
Word Identification in grade 1		.56	.07	.54***
Awareness in grade 1		6.98	1.33	.37***
Step 3	.67			
Word Identification in grade 1		.46	.07	.44***
Awareness in grade 1		8.04	1.30	.42***
Naming in grade 1		−4.18	1.19	−.22**
Step 4.	.70			
Word Identification in grade 1		.43	.07	.41***
Awareness in grade 1		7.05	1.28	.37***
Naming in grade 1		−3.68	1.15	−.19**
Letter Recognition in grade 1		.41	.13	.19**
Grade 3				
Step 1	.83			
Word Identification in grade 2		.79	.04	.91***
Step 2	.85			
Word Identification in grade 2		.74	.04	.85***
Analysis in grade 2		2.31	.77	.14**
Step 3	.86			
Word Identification in grade 2		.71	.04	.82***
Analysis in grade 2		2.44	.74	.14**
Naming in grade 2		−1.96	.68	−.12**
Step 4	.87			
Word Identification in grade 2		.68	.04	.78***
Analysis in grade 2		2.16	.74	.13**
Naming in grade 2		−1.71	.68	−.10*
Letter Recognition in grade 2		.94	.48	.09*

Table 7 (continued)

Variable	R^2	*B*	*SE B*	β
Step 5	.88			
Word Identification in grade 2		.72	.04	.82***
Analysis in grade 2		2.10	.71	.12**
Naming in grade 2		−1.60	.65	−.10*
Letter Recognition in grade 2		1.68	.51	.16**
Letter Recognition in grade 1		−.28	.09	−.15**
Step 6	.89			
Word Identification in grade 2		.71	.04	.81***
Analysis in grade 2		2.11	.69	.13**
Naming in grade 2		−1.41	.64	−.08*
Letter Recognition in grade 2		1.70	.50	.17**
Letter Recognition in grade 1		−.30	.09	−.16**
Memory in K		1.36	.59	.09*

Note. *$p<.05$. **$p<.01$. ***$p<.001$.

Letter Recognition was .39 and .51 in grades 1 and 2 respectively, indicating that these two tasks explained largely overlapping variance.

Two odd features of the results in Table 7 are worth noting. First, Word Attack did not predict Word Identification significantly at any grade. This is most plausibly an artifact of multicollinearity in these data: the correlation between these two measures was .89 or higher in each grade. Because Word Identification was always entered first into the analyses, Word Attack had little unique variance left to explain. Second, in steps 5 and 6 of the grade 3 analysis, grade 1 Letter Recognition appeared as a negative predictor, following grade 2 Letter Recognition as a positive predictor. This again is also most probably due to multicollinearity, the correlation between the two Letter Recognition scores being .58. Having accounted for 87% of the variance, there may be little left to explain but error.

Table 8 summarizes the results from the hierarchical linear regression analyses predicting the Passage Comprehension score in grades 1, 2, and 3. As with Word Identification, the autoregressors accounted for the largest share of the Passage Comprehension variance at all grade levels. Specifically, kindergarten Word Identification and Letter Recognition explained over 80% of the grade 1 Passage Comprehension variance. Although kindergarten Word Attack, Awareness, and Naming were also significant predictors, they accounted for only 2% of additional variance above that accounted for by the two autoregressors.

In grade 2, the R^2 increased by .12 when grade 1 Awareness was added to the model and by another .10 when grade 1 Naming and Letter Recognition and kindergarten Awareness were added to the model. In grade 3, adding grade 2 Analysis and grade 1 Rhyming into the model increased R^2 by only .04.

The effects of multicollinearity appear at two points in Table 8. Word Attack is a negative predictor in grade 1, after the autoregressors accounted for 83% of the variance, and the kindergarten Awareness factor is negative in grade 2 after

Table 8
Summary of Hierarchical Regression Analyses for Variables Predicting Passage Comprehension in Grades 1, 2, and 3

Variable	R^2	*B*	*SE B*	β
Grade 1				
Step 1	.83			
Word Identification in K		.58	.03	.81***
Letter Recognition in K		.11	.02	.19***
Step 2	.84			
Word Identification in K		.75	.06	1.05***
Letter Recognition in K		.10	.02	.17***
Word Attack in K		−.47	.15	−.26**
Step 3	.85			
Word Identification in K		.71	.06	.99***
Letter Recognition in K		.08	.02	.14**
Word Attack in K		−.45	.15	−.24**
Awareness in K		1.13	.44	.12*
Step 4	.86			
Word Identification in K		.64	.06	.90***
Letter Recognition in K		.05	.02	.09*
Word Attack in K		−.36	.15	−.20*
Awareness in K		1.66	.46	.17***
Naming in K		−1.19	.37	−.13**
Grade 2				
Step 1	.47			
Passage Comprehension in grade 1		.71	.08	.68***
Step 2	.59			
Passage Comprehension in grade 1		.51	.08	.49***
Awareness in grade 1		4.11	.74	.40***
Step 3	.64			
Passage Comprehension in grade 1		.38	.08	.37***
Awareness in grade 1		4.80	.72	.47***
Naming in grade 1		−2.63	.68	−.25***
Step 4	.67			
Passage Comprehension in grade 1		.35	.08	.34***
Awareness in grade 1		4.28	.72	.42***
Naming in grade 1		−2.39	.67	−.23**
Letter Recognition in grade 1		.21	.07	.18**
Step 5	.69			
Passage Comprehension in grade 1		.45	.09	.43***
Awareness in grade 1		5.04	.78	.49***
Naming in grade 1		−2.08	.67	−.20**
Letter Recognition in grade 1		.21	.07	.18**
Awareness in K		−1.88	.82	−.19*

Table 8 (continued)

Variable	R^2	*B*	*SE B*	β
Grade 3				
Step 1	.57			
Passage Comprehension in grade 2		.66	.06	.75***
Step 2	.59			
Passage Comprehension in grade 2		.58	.07	.67***
Analysis in grade 2		1.59	.71	.17*
Step 3	.61			
Passage Comprehension in grade 2		.59	.07	.67***
Analysis in grade 2		1.50	.69	.16*
Rhyming in grade 1		1.73	.75	.15*

Note. *$p<.05$. **$p<.01$. ***$p<.001$.

the grade 1 Awareness score is entered. Given the strongly positive correlations between these predictors, these results should be taken to mean that the limits of prediction have been reached.

In sum, autoregressors accounted for most of the variance of both Word Identification and Passage Comprehension. However, at least two phonological processing scores were significant predictors of every outcome, even after the autoregressive effect was accounted for. Naming and Awareness (or, in grade 2, Analysis) were the most frequent predictors, appearing in almost every analysis.

Discussion

Our discussion focuses first on what these results have to say about theories of reading, and second on the implications for assessment and teaching in practice.

The argument underlying this article is that comprehensive theories of achievement constructs will help solve many potentially perplexing problems in educational measurement. Theory in the area of early reading has advanced to the point that we are confident in proposing the list of constructs shown in Figure 1, and not least in the domain of phonological processing. The results confirm the broad outline of what is shown in Figure 1, in that several measures of phonological processing and letter knowledge were shown to be significant predictors of reading progress even after accounting for the autoregressive effect of the previous year's reading score. It should be emphasized how conservative an approach this is. The previous year's achievement score is the result of the full range of other individual differences, instruction, and home factors. To show, for instance, that grade 1 phonological awareness is a significant predictor of grade 2 word reading, after taking account of grade 1 word reading, is to indicate that phonological awareness is playing a special and important role. The only construct shown in Figure 1 that did not emerge as a significant predictor in the present results was "pronunciation by analysis knowledge" or, more simply, decoding. This construct was represented by the Word Attack score in this study. Other measures, perhaps of strategy use, may have added to the prediction. It is important to remember that Word Attack was highly correlated with the other reading achievement scores to the point that it had little to contribute after the autoregressors. These results provide no reason to discount the importance of decoding skills.

Although we are confident in proposing the list shown in Figure 1, we are less certain about the internal structure of the phonological processing domain and of the causal connections between it and letter knowledge and decoding. In other work (Kirby et al., 1995) we have argued for the particular sequence shown in Figure 1 (with some further direct links between nonadjacent constructs, and allowing the possibility of reciprocal links), and some support has been provided (Beggs, 1996; James, 1996). We are continuing to investigate this and other models with our longitudinal data.

The particular phonological constructs that emerged most frequently as predictors are worth noting. Awareness (or Analysis) is the most advanced of the phonological constructs, developing the latest (Wagner et al., 1993) and being the most similar to reading in that it requires operation at the phonemic level. Awareness may represent overall development in the phonological domain; there is no lack of evidence that those who lack it are not doing well in reading and are not likely to begin to progress soon (Adams, 1990; Torgesen et al., 1994). Naming is a different construct, beginning development much earlier and being measured more in terms of efficiency. Recent evidence suggests that some children do poorly in reading because of slow naming speed in spite of adequate phonological awareness (Bowers, Sunseth, & Golden, 1999; Kirby, Etmanskie, Parrila, & Das, in preparation; Wolf, 1997).

The primary implication for practice emerging from this research is that we have identified important constructs involved in learning to read and have identified effective indicators of those constructs. These indicators did not involve any reading and were administered a year or more before the outcome measures. Furthermore, most of the constructs have straightforward relationships with their indicators. By this we mean that the indicators have face validity and construct validity as measures of the constructs and that it is difficult to imagine a child being able to perform the measures successfully without having an adequate amount of the construct in question.

These constructs are appropriate targets for assessment and instruction. These constructs, or rather their indicators, are the right tests to teach to, at least during the early years of school. If teachers modify their teaching to target these tests, little harm should occur. It would be important to keep in mind further reading development toward more elaborate forms of comprehension, and not focus only on the early stage. A greater and more theory-based focus on the early stage, however, would provide a stronger basis for such further development.

Does early reading achievement provide a model for other areas of educational achievement? Can similarly detailed theoretical models of achievement be developed in other areas, and can such valid and straightforward indicators be identified? Both of these goals seem attainable in early mathematics skills, where knowledge of simple number facts seems critical for further achievement (Kirby & Becker, 1988). Reading comprehension has yielded quite sophisticated theoretical models lately (Kintsch, 1998), but it is not yet clear how these theories would lead to classroom or standardized assessment. Biggs and Collis' (1982) SOLO Taxonomy may offer both a theoretical model and a method to derive valid assessment in areas as diverse as the humanities and the sciences.

The article illustrates in early reading the value of developing a comprehensive and detailed theoretical model of achievement tasks and the importance of deriving useful indicators of the theoretical constructs. We believe that real progress has been made in this area and that it is no longer justified to ignore this work when developing curriculum and assessment. We hope that other areas of educational achievement will proceed in the same direction.

Acknowledgments

The authors wish to thank Dariush Araï for advice on regression analyses and Richard Wagner and J.P. Das for making some of the tests available. This research was supported by the Social Sciences and Humanities Research Council of Canada with a grant to John R. Kirby and J.P. Das and a postdoctoral fellowship to Rauno K. Parrila.

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