Foundations Learning System: The Varied Practice Model

White Paper

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August, 2019

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Foundations in Learning

Why do we need a new approach to reading assessment and intervention?

Reading is the most critical foundational skill for academic and professional success. Effective and efficient reading serves as a springboard for learning other skills and disciplines. As Slavin and colleagues noted, "Those who succeed in becoming fluent, strategic, and joyful readers are not guaranteed success in school or in life, but they are well on their way. However, those who do not succeed in reading, or who become reluctant readers, face long odds in achieving success in school and life" (Slavin, Lake, Chambers, Cheung, & Davis, 2009, p. 1391). Tragically, huge numbers of American students fall short of achieving reading success, limiting their potential. Too many students are missing the essential reading abilities they need for academic and career success. A better approach is needed to help these students learn to read.

The 2017 National Assessment of Educational Progress (NAEP) found that only 37% of fourth graders and 36% of eighth grade in the United States reached reading proficiency (US Dept. of Education, 2017). Nearly two-thirds of students are entering high school with poor ability to read text for content. Troublingly, research suggests that approximately half of these struggling readers have deficits in foundational reading skills, which should have been mastered in elementary school (Cirino et al., 2013; Hock et al., 2009). By middle school, many of these students have minimal access to specialists who know how to train their missing foundational skills, and they are rapidly running out of time to catch up to grade-level expectations. Without an approach that remediates their reading deficits, these students face a major uphill battle to succeed.

Reading deficits particularly affect students of color and those from less advantaged backgrounds. Only 18% of black eighth graders and 23% of Hispanic eighth graders showed reading proficiency, compared to 45% of white students. Students who qualify for the National School Lunch Program (NSLP) showed much greater risk of reading deficits: only 21% of NSLP-eligible eighth graders were proficient, compared to 48% of non-eligible students. English language learners show particular challenges; only 5% of these students in the NAEP eight-grade sample demonstrated reading proficiency. Yet the challenges extend beyond disadvantaged groups, as seen by the low proficiency rates among non-NSLP-eligible students. Similarly, even among children whose parents have college degrees, only 47% of eighth graders reached proficiency.

In addition to the ubiquity of reading deficits among students, these deficits show persistency throughout children's school years. The NAEP report found that rates of proficiency among fourth grade students (37% were proficient) were quite similar to the rates of eighth graders. Further, research shows within-child stability of reading difficulty. Longitudinal studies show that students who lag behind their peers in reading at early grades show comparable (Shaywitz et al., 1995) or exacerbated (Cain & Oakhill, 2011) deficits in reading at later grades, and these deficits often lead to downstream difficulty with higher level academic skills (Duff, Tomblin, & Catts, 2015).

Practitioners thus face parallel challenges: identify struggling readers early to quickly improve foundational skills, and develop ways to remediate skills of students who reach middle school without adequate reading skills. The Foundations Learning System was designed to address these parallel needs, with assessment and intervention options for students from 2nd grade through middle school, and content and delivery approaches that are designed to the specific needs of these students.

Why does the Foundations Learning System emphasize decoding and automaticity?

A consensus of researchers and practitioners suggest several critical components to target for reading instruction and intervention. The National Reading Panel identified five critical areas for effective early reading instruction: phonemic awareness, phonics, fluency, vocabulary and comprehension (National Reading Panel, 2000). These same areas were emphasized by the US Department of Education in their 2009 Practice Guide (Gersten, 2009). Although these are discussed as independent pillars for reading ability, there is substantial interdependence between these skills. The Foundations Learning System specifically targets the development of phonics knowledge and automatic use of this knowledge, as these skills are critical for the acquisition of higher-level reading abilities; without these foundational abilities to rapidly and accurately read words, higher level reading skills are impossible.

A startling number of struggling middle school readers lack the foundational reading skills that are precursors to reading fluently and effectively (Cirino et al., 2013; Hock et al., 2009). Although fluent reading relies on a constellation of many skills, the lack of these foundational skills is particularly damning for an aspiring reader. Shankweiler and colleagues noted that decoding abilities were extremely predictive of reading comprehension, with decoding accounting for substantially more variance in comprehension than even spoken language comprehension (Shankweiler et al., 1999). Basic reading ability is particularly important for struggling readers; whereas skilled readers show little relationship between word reading ability and comprehension, a strong predictive relationship exists for struggling readers through middle school (Oslund, Clemens, Simmons, & Simmons, 2018).

These findings suggest that decoding intervention may be critical to achieving effective comprehension. Indeed, further research bears this prediction out; a randomized control study of students aged 7 to 10 showed that an intervention focusing on decoding skills also boosted reading comprehension scores (McCandliss, Beck, Sandak, & Perfetti, 2003; see Foorman, Francis, Fletcher, Schatschneider, & Mehta, 1998 for similar results). This study identified students with decoding deficits, and provided a subset with 20 sessions of targeted decoding training. The students in the training group showed substantial gains between pretest and posttest, with an average improvement of 6.3 percentiles in a standardized score of passage comprehension. Meanwhile, the untrained group showed a slight decline from pretest to posttest (-1.3 percentiles). Emphasis on foundational decoding skills in this study had a clear benefit for high-level reading comprehension ability.

The need for decoding skills in order to read with comprehension might be unsurprising – in order to comprehend a text, a student needs to be able to identify the component words. However, decoding on its own is insufficient to create an effective reader. Reading text for comprehension demands that the reader focus cognitive resources on understanding the content of the text, particularly as texts become more complex. The need to read for content in middle school and high school is predicated on students' ability to extract new knowledge from texts, and to integrate this knowledge into discipline-specific understanding. Sounding words out one-by-one precludes the ability to produce a fluent reading of multi-word strings of text, which both slows reading and impedes the ability to focus cognitive resources on the content of the text. A reader who must devote substantial cognitive resources on decoding will struggle to interpret the meaning of the words she reads.

As such, decoding on its own is insufficient to elicit skilled, fluent reading. Effective readers must be able to recognize words automatically and effortlessly, freeing cognitive resources for use in reading comprehension (Oslund et al., 2018). Reading without automaticity is akin to doing arithmetic by counting on one's fingers. Although counting fingers can allow an early learner to effectively complete simple addition problems, faster and more automatic addition (adding in their head) is necessary to use this knowledge in more complex math problems. A fluent reader needs to be able to read without focusing effort on each specific sound-letter pairing, just as an effective math student needs to be able to solve problems without doing each piece of arithmetic on her fingers.

This concept of automaticity of deployment of decoding knowledge is often thought of as the natural end-state of learning to decode; with enough decoding practice, the child will become automatic. However, recent research has shown automaticity to be a unique and reliable predictor of word reading fluency for middle school readers, over and above decoding skill (Roembke, Hazeltine, Reed, & McMurray, 2019) – automaticity is not simply high decoding skill. This study assessed the degree to which traditional decoding measures can predict fluency outcomes, and then demonstrated that novel measures crafted specifically to assess automaticity predicted additional variance in the fluency measure. This finding suggests that automaticity is indeed a separate, measurable component of fluency. The most fluent readers are those who know the decoding rules, and who have considerable skill deploying this knowledge automatically. The Foundations Learning System embraces this emphasis on automaticity as a separate construct from decoding and uses the same tasks as this study to train and measure automaticity.

Although fluent reading and strong reading comprehension require more than automatic word recognition, they are impossible without strong foundational reading skills. Unfortunately, many of the middle school students struggling to read have little opportunity to receive support for deficits in foundational skills. Middle school educators are rarely trained to identify and teach basic decoding abilities, as these abilities are typically the purview of early elementary school. Additionally, explicit attempts to build automaticity of word recognition are exceedingly rare, both within primary school education and in later intervention efforts. Many struggling middle school readers receive interventions that focus predominantly on comprehension – decoding is rarely directly measured, much less targeted for intervention. Within approaches that emphasize decoding training, few specifically target automaticity as a specific extension of decoding. Although many products hope to achieve automatic word recognition, the field of reading education has not developed an effective definition or measure of automaticity, much less a theoretical model of how to train it. The extant approaches rely on the hope that automaticity will arise naturally with enough decoding training; unfortunately, the science of learning suggests that such an approach is likely misguided. To this end, the Foundations Learning System emphasizes building the foundational skills needed to achieve automatic word recognition. The screener and diagnostic components of the Foundations System help identify students with persistent foundational deficits, allowing targeted remediation for these students. This approach allows students to receive the specific help they need to build the foundations for fluent reading.

What does it mean to train automaticity?

Automatic word recognition refers to the ability to read a word without relying on effortful decoding. This ability is a goal of most reading pedagogies, as students need to read quickly and effortlessly to be able to read content for meaning. Similarly, most theories of reading acquisition emphasize this goal of automatic word recognition. For example, two of the most prominent computational accounts of reading development, the Dual-Route Cascade (DRC) Model (Coltheart et al., 2001) and the connectionist Triangle Model (Harm & Seidenberg, 1999; Plaut, McClelland, Seidenberg, & Patterson, 1996) both strive to explain how readers can link words to their meanings without passing through slow connections to phonological representations – that is, how readers can learn to directly access word meaning from orthographic forms. Although the mechanisms of these models differ, both accounts envisage the end-state of effective reading as the ability to rapidly read words with minimal effort. Indeed, this seemingly effortless ability to recognize words is a hallmark of skilled reading – effective readers can process large quantities of text quickly, with little conscious processing of letter-to-sound mappings.

Despite the acknowledgement that automatic word recognition occurs for effective readers, few approaches attempt principled means of training automaticity. Instead, automaticity is often assumed to arise naturally from sufficient learning and experience; if a learner gets good enough at decoding, she is expected to begin to decode automatically. However, substantial work in other cognitive domains suggests that building automaticity may benefit from methods that differ from those used to master explicit knowledge of basic skills. Although traditional mastery models may build strong explicit understanding of the components of decoding, engaging these components for automatic use by implicit mechanisms may require a different approach.

Automaticity has been investigated in a number of non-reading cognitive domains, leading to general principles that are likely to apply to the development of automaticity in reading. A common refrain from these studies is that training automaticity often demands different approaches than training explicit knowledge. These findings suggest that effective training of automatic word recognition likely requires more than exhaustive decoding training.

The development of automaticity has been most thoroughly studied in motor learning (e.g., Romito, Krasne, Kellman, & Dhillon, 2016; Wulf, Shea, & Lewthwaite, 2010; Wulf & Su, 2007). Many motor domains require learning to produce motor actions without explicit thought. Complex motor skills that encompass multiple basic skills require a series of actions that need to be coordinated to produce fluent outcomes. For example, a skilled basketball player needs to be able to dribble the ball with minimal thought, so that cognitive resources can be devoted to higher order challenges, like planning a pass to a moving teammate. A need for conscious effort for each component action would make coordination of multiple actions quite difficult and prevent the deployment of these skills in complex settings. As such, substantial research on motor skill development has emphasized how to train implicit, automatic skill use.

As an example, consider training a surgeon to perform the basic motor components of surgery, such as making incisions (Wulf et al., 2010). Substantial skill at making incisions is crucial for successful surgery. However, effective surgery has numerous cognitive demands beyond these basic tasks: the surgeon must also monitor the patient's well-being, respond to changing feedback about the procedure, coordinate with other practitioners in the room, and so on. As such, an effective surgeon needs to be able to complete basic surgical actions without overtaxing cognitive resources that are needed for higher order tasks. A traditional mastery approach would suggest that building automaticity in the basic abilities should arise from repeated focused practice on the motor action – if the surgeon practices making incisions often enough, she will integrate these motor skills into her implicit motor knowledge. However, research contradicts this wisdom; whereas repeated, effortful practice helps aspiring surgeons build *explicit* knowledge of how to perform actions, this method is not ideal for building *implicit* or *automatic* use of this knowledge (Wulf et al., 2010). Instead, automaticity of motor skills arises more effectively from tasks that draw attention away from the explicit motor task. When learning surgical skills, students develop better automaticity when they are instructed to focus on the outcome of these actions rather than on the specific procedural actions themselves. Similarly, when learning golf swings, golfers show improved performance when instructed to focus on the motion of the golf club rather than on their arm movements – that is, when they focused on *using* their motor skills, rather than the motor movements themselves, they showed better growth of automatic skill deployment (Wulf & Su, 2007).

These findings suggest that the development of automaticity may require two contrasting learning approaches. On one hand, the learner needs to master basic procedural skills at an explicit level; the doctor needs to understand what a proper incision entails, and the reader needs to understand how letters link to the sounds of her language. Simultaneously, the learner needs to integrate this information into their cognitive processing system, such that she can deploy the knowledge effortlessly; the doctor needs to make proper incisions with minimal thought, and the reader needs to access word meaning without devoting substantial cognitive resources to decoding. The motor learning work suggests that these parallel tracks may benefit from different forms of training (Wulf & Shea, 2002).

An approach to training these parallel tracks in more cognitive domains comes from research on perceptual learning. Perceptual learning refers to a learner's ability to extract statistical regularities in patterns of input, typically through implicit means; this implicit awareness of regularities is precisely the type of learning needed to use knowledge quickly and automatically in diverse settings. Classic findings in perceptual learning show a dissociation between explicit and implicit pattern learning. Specifically, explicit learning is often highly effective for simple patterns, such as those where a single feature distinguishes categories – if the learner can make a simple, verbal rule, such as "all short lines are in Category 1 and all long lines are in Category 2." However, more complex patterns are better learned implicitly (Ashby & Maddox, 2005). If a simple verbal rule is impossible (e.g. for distinctions that are signaled by multiple features), then learners perform better without explicit learning. In some cases, learning is *improved* when explicit learning is prevented; forcing learners to rely on implicit learning rather than explicit learning helps them acquire information that is readily deployed.

These concepts apply surprisingly well to educational domains. Kellman and colleagues show that embracing implicit perceptual learning can greatly improve learning in numerous domains that are traditionally thought to be best taught through explicit means, including classroom mathematical concepts (Kellman et al., 2008; Kellman, Massey, & Son, 2010), medical concepts (Romito et al., 2016), and aviation (Kellman & Kaiser, 1994). Kellman argues that even explicit knowledge, like how to divide fractions, can be boosted by improved implicit representations to support more fluent use of this knowledge. The explanation for this counterintuitive claim echoes the goals needed for fluent reading: whereas explicit knowledge can help students understand the operations they need to complete, implicit ability to use this knowledge can help them decrease their cognitive load when using their knowledge and deploy this knowledge flexibly. Kellman and colleagues refer to the distinction of *discovery*, when the learner is first acquiring knowledge, and *fluency,* when the learner is becoming automatic at using this knowledge. These stages are attested in reading, with discovery of the rules mapping letters to sounds, and fluency of using this knowledge smoothly and quickly in connected text. The most accomplished students are those who have completed both stages: they both know the material and are skilled at using it.

The training studies by this group demonstrate the benefit of these parallel learning tracks. In their perceptual learning interventions, students show remarkable gains in their ability to flexibly and rapidly use their explicit knowledge. Critically, these gains in how automatically they use their knowledge arise even for students with substantial existing knowledge. For example, in a study of aviation knowledge, pilots with hundreds of hours of flight experience received brief perceptual learning training. After this training, they completed basic aviation tasks around 60% faster, despite years of prior experience (Kellman & Kaiser, 1994). The perceptual learning training helped these skilled pilots better deploy their knowledge. Similar results emerged for high school algebra students (Kellman et al., 2008); students who were already able to complete algebra problems accurately showed a nearly 50% improvement in response speed after brief perceptual learning training. The training allowed the students to use their explicit knowledge more automatically.

These perceptual learning studies have clear parallels in the reading domain. Reading benefits from explicit training of decoding knowledge (Ehri, Nunes, Stahl, & Willows, 2001), yet it also has highly complex patterns that are often hard to verbalize (Plaut et al., 1996) – akin to the multidimensional categories from classic perceptual learning research. Learners need to understand how letters map to sounds, but they also need to deploy this knowledge automatically to apply the knowledge to diverse words in connected text. As suggested by the research from motor learning and perceptual learning, building this automaticity requires going beyond overtraining on explicit learning, and instead engaging implicit learning systems.

The Foundations Learning System takes a proactive approach to achieving this, helping build both decoding skills and automatic deployment of these skills in word recognition. As in the perceptual learning work detailed above, this approach is intended to supplement explicit teaching of the regularities; the Foundations System helps learners strengthen this knowledge and use it effectively. Decoding is trained through a series of tasks that emphasize explicit awareness of letter-sound correspondences. Interspersed with these decoding tasks are tasks that emphasize the development of automaticity of word recognition by guiding learners to deploy their decoding knowledge rapidly and flexibly. These tasks discourage slow, effortful decoding, and thus encourage the learner to become adept at using implicit means to quickly decode the items. In addition, the varied practice approach, detailed below, highlights relevant contrasts, helping learners acquire implicit awareness of GPC regularities. Finally, the adaptive nature of the Foundations Learning System ensures that the nature of these tasks reflects a learner's current ability levels. Learners with very poor decoding abilities face reduced pressure in the automaticity tasks and simpler contrasts, as they need to learn the explicit skills before they can be expected to deploy this knowledge automatically.

What is the Varied Practice Model?

The Varied Practice Model (VPM) is a learning-theoretic approach that emphasizes training diversity to boost learning. The theory suggests that exposure to variable training items and contexts creates more robust memory representations, leading to better retention and more flexible recall. The VPM stands in contrast to a classic mastery model of learning, in which specific items or classes are trained exclusively until mastery; under a mastery model, training is conducted in blocks of specific material until the learner shows full understanding of this material, rather than interleaving content during learning. The VPM alternatively emphasizes interleaving material throughout learning. This approach has found support in a wide range of training settings, from motor skill learning to concept learning, suggesting that it operates as a fundamental principle of learning. The Foundations Learning System embraces the VPM framework as a means of building robust, flexible representations of phoneme-grapheme correspondences among students, as fluent, automatic reading demands such encoding.

The VPM builds on a substantial body of research demonstrating considerable impacts of stimulus and context variability during learning. These effects arise from extremely young ages:

Rovee-Collier and Dufault demonstrated that three-month-old infants generalize learning across new contexts only if they first experience information in varied settings (Rovee-Collier & Dufault, 1991). If the infants learned in a single setting (in this case, in a single crib with constant ambient surroundings), they failed to generalize their learning to new environments. Similar findings emerge for early language learning: Rost and McMurray found that 14-month olds were better able to learn novel words if they heard them in multiple voices (Rost & McMurray, 2009, 2010). When training involved hearing two highly similar novel words (*buk* and *puk*) in a single voice, infants failed to learn to them as different words. The same words presented in seven distinct voices led to better differentiation of the items. Despite voice being irrelevant to word identity, infants better learned novel words in the context of varying voices.

Similar benefits of varied practice emerge for skill learning. Kerr and Booth (1978) examined the impact of variability on a simple motor skill: throwing a bean-bag at a target. They trained one group with practice trials only at the distance they would be tested at, and another group with practice trials at a variety of distances. The group with variable training showed better performance at test – even though the group with specific training received more training at the specific test distance, the varied training led to better performance at this distance. Extensions of this work showed similar benefits from variability of the weight of the bean-bag used in training (Pigott & Shapiro, 1984). Similar effects arise for other skill domains, including learning to make rapid button-presses in response to visual stimuli (Catalano & Kleiner, 1984), learning to land a plane (Huet et al., 2011) and for injured cats re-learning how to walk after a spinal-cord injury (Cai et al., 2006).

These benefits of varied training demonstrate the value of experiencing information in multiple settings. Classic cognitive research on context dependency in learning has shown that memory suffers when testing occurs in different contexts than learning (Farnsworth, 1934; Pessin, 1932). This research suggests that despite its irrelevance for the information being encoded, contextual information (like the room in which information was studied) gets encoded with the learned information. However, this context dependency dissipates when training occurs in varied contexts (Smith, 1982; Smith, Glenberg, & Bjork, 1978). Whereas constant contexts lead learners to develop strong (but unnecessary) links to the training context, variable contexts instead allow context-invariant representations to form, which allow learning to generalize to new contexts.

Variability also aids learning in academic settings. For example, when learning to identify artists by their painting styles, learners show notably better performance if their training involves interleaving of paintings by different artists, rather than massed blocks of individual artists (Kang & Pashler, 2012; Kornell & Bjork, 2008). The trial-by-trial variability of the former condition produced better performance both for the paintings used during training and generalization to novel paintings by the same artists, and even improved learners ability to discriminate between paintings by the artists used in training and artists not encountered in training. Intriguingly, participants predicted that their learning was better with massed blocks of training (Kornell & Bjork, 2008); the benefit of trial-by-trial variability arises without metacognitive awareness.

Varied practice shows similar benefits for standard classroom learning. Rohrer and Taylor (2007) demonstrated improved learning of mathematical formulas by college students if training involved a mixture of different problem types, rather than successive blocks of individual problem types. Although the practice schedule with blocks of the same problems boosted performance immediately after lessons, the former approach of mixing problem types showed enormous benefits when testing a week later, with the group receiving mixed training performing around

250% better than the blocked group. The varied practice approach led to substantially better long-term retention of the material.

More pertinent to the Foundations Learning System, evidence demonstrates benefits of varied practice within the reading domain as well. When learning vowel grapheme-phoneme correspondence (GPC) regularities, first-grade students showed better performance after training on a highly variable set of items than after training on a set with less variability (Apfelbaum, Hazeltine, & McMurray, 2013). In this study, students were taught a set of vowel GPC regularities, and variability was manipulated in the consonant contexts the vowels occurred in during practice. For the non-variable group, there was high similarity between consonants in the training items (e.g. bat, hat, bit, hit); in the variable group there was less overlap between training items (e.g. fan, pat, sit, wig). The group with greater variability of consonants showed improved learning of the vowel regularities. This variability benefit emerged despite the same overall amount of training between the two groups, and the benefit was surprisingly consistent: variable training showed better outcomes for both trained items and novel items; for trained tasks and novel tasks; and for learners who began the study with poor reading abilities and those with stronger reading abilities. Varying practice in this instance showed a clear, broad benefit for early acquisition of reading skills.

Why does varied practice work?

The diverse findings of benefits of varied practice demonstrate its utility for training new knowledge and skills, but harnessing these benefits for maximum impact may require better understanding of *why* varied practice leads to such effective outcomes. Several explanations for why varied practice improves learning have been suggested. These explanations consider low-level perceptual benefits, as well as higher level cognitive benefits; critically, these explanations are not mutually exclusive, as variability might benefit learning at multiple levels.

Varied practice may help learners subconsciously identify which information is most relevant in a learning task. For example, Rost and McMurray (2009, 2010) found that infants better learned novel words in the context of wide variability of irrelevant auditory information (e.g. the person who said the words, or the tone of voice in which words were spoken). These results were interpreted as increased irrelevant variability guiding infants to ignore variable acoustic dimensions in favor of more consistent dimensions (Apfelbaum & McMurray, 2011). As the infants learned the lexical categories, the degree of variability guided them to pay closer attention to the most consistent (and most relevant) pieces of information.

Alternative explanations of variability benefits hinge on the role of item-by-item contrast invoked by variability. Hammer and colleagues neatly detailed an information-theoretic account of when variability should be most beneficial, stressing situations in which learners need to discriminate items from contrasting categories (Hammer, Bar-Hillel, Hertz, Weinshall, & Hochstein, 2008; Hammer, Diesendruck, Weinshall, & Hochstein, 2009). In this account, variability between items is maximally informative when it allows learners to identify small differences between similar categories. Kornell and Bjork (2008) demonstrate this benefit in a study of learning painting styles. They found substantially improved learning when paintings by different artists were interleaved, rather than presenting blocks of paintings by a single artist. This interleaved presentation format allowed learners to focus on the critical distinctions between styles, rather than seeking undefined commonalities in a set of paintings by a single artist. Thus the local varied practice of interleaving artists aided learners' ability to identify relevant contrasts.

This explanation of varied practice predicts that variability should be acutely helpful in cases of difficult contrasts; as Kurtz and Hovland (1956) argue, “when the degree of discriminability is low, it might be expected that placing of instances from different concepts in juxtaposition would facilitate discrimination learning, whereas with greater discriminability, like that obtaining in the present study, the reverse might obtain” (p. 242). The GPC regularities in reading seem to fit the description of low-discriminability contrasts – readers must identify regularities that are highly context specific (e.g. –EAD usually makes a short-e sound, whereas –EA in other contexts makes a long-e sound), and there is substantial overlap of regularities (e.g. the letter A can map to numerous sounds depending on how it’s paired with other letters: BAT, BAIT, BOAT).

Is varied practice appropriate for reading interventions?

The evidence in support of the varied practice model comes from a wide range of domains. Many of these studies use tightly controlled laboratory experimental design, raising some concerns about translation to the classroom setting. However, several pieces of evidence support the value of applying this learning model to reading interventions.

The most straightforward support for varied practice as useful for reading education comes from studies that directly apply this model to academic material. As summarized above, studies have demonstrated variability benefits for teaching students to learn artists’ styles, for successful learning of novel mathematical formulas, and for acquisition of basic GPC skills in reading (Apfelbaum et al., 2013; Kang & Pashler, 2012; Kellman et al., 2008, 2010; Rohrer & Taylor, 2007). These studies support the notion that varied practice benefits generalize to academic material; using these concepts *in situ* offers substantial promise for improving outcomes.

Additionally, there are theoretical arguments in support of varied practice as a valuable tool for reading interventions. Substantial empirical and computational research supports the view of that reading relies on statistical learning mechanisms (Arciuli & Simpson, 2011; Harm & Seidenberg, 2004) – learning to read in a quasi-regular orthography like English requires developing sensitivity to subtle statistical patterns in the input. Many of the theoretical accounts of variability benefits rest on statistical learning bases (e.g., Apfelbaum & McMurray, 2011; Gómez, 2002; Perry, Samuelson, Malloy, & Schiffer, 2010), such that variability leads to massive benefits in learning complex statistical structures. Thus a statistical-learning view of reading would suggest that variability is extremely likely to boost learning. If learners are extracting information about the GPC regularities of English through sensitivity to the statistical patterns, then variability in information sources will play a crucial role in shaping learning.

Arciuli and colleagues found clear links between children’s statistical learning ability and their reading outcomes, suggesting that reading acquisition relies on some domain-general forms of statistical pattern sensitivity (Arciuli & Monaghan, 2009; Arciuli & Simpson, 2011; Kemp, Nilsson, & Arciuli, 2008). The need for statistical pattern recognition for reading becomes apparent when considering the *quasi-regular* patterns of GPC regularities in English (Plaut et al., 1996). Learners need to not just learn hard-and-fast rules, but also more nuanced sub-patterns in how these rules apply in different contexts. For example, readers can’t simply learn that the sequence EA always makes the long-e sound, as this pattern followed by a D (as in HEAD and BREAD) often leads to a short-e sound. Critically, this isn’t a pure rules-and-exceptions system; the contexts in which EA makes the short-e sound are predictable, so learning context-sensitive patterns can greatly boost reading ability. A skilled reader thus needs to be highly sensitive to contextual variations in the patterns of the orthographic system.

Computational models of reading acquisition echo this endorsement of a statistical approach to theories of reading. Harm and Seidenberg (2004) developed a connectionist simulation of reading development that captures developmental patterns of learning quite effectively. This model used simple statistical connections between representations to simulate learning of GPC mappings – that is, the model relied on principles of statistical learning as the basis of how children learn to read. Critically, this model also showed sensitivity to varied practice: when the model learned with blocked presentation of items, its learning was fragile, whereas interleaved presentation of many training items elicited more robust pattern learning.

The substantial body of evidence demonstrating statistical learning bases in reading lead to a clear expectation of variability benefits when learning to read. Because readers need to uncover subtle statistical patterns in the mappings between letters and sounds, training in conditions of high variability should great boost acquisition of this knowledge.

How does the Foundations Learning System use the Varied Practice Model?

The Foundations Learning System embraces the use of varied training in several intersecting ways to build robust, generalizable knowledge of GPC regularities. First, the Foundations System embeds items exemplifying the GPC regularities in a wide array of tasks. Task variability requires learners to apply their budding knowledge in diverse ways, which helps learners build representations that are readily deployed in different settings. Skilled reading requires flexible use of reading knowledge for different tasks; a strong reader displays automatic word recognition when reading words in isolation and reading connected text, and can use this knowledge for perception (when reading words) and in production (when writing words).

These various task demands map onto different "pathways" for reading – that is, they require links between different types of knowledge representations (e.g., Plaut et al., 1996). For example, a spelling task, in which the learner must spell a word or a non-word in response to hearing it, targets mappings between phonology and orthography. A find-the-picture task, in which a learner must identify which picture matches a printed word, targets the ability to link orthography to meaning. By assessing and training each of these pathways with overlapping item sets, the Foundations Learning System can build generalizable reading skills, in which learners develop robust learned representations that reflect the assortment of ways that learners may need to access their reading knowledge.

Variability also arises in the Foundations Learning System from use of diverse stimulus sets used in training. Within a given type of learning, a highly disparate set of words is used to encourage learners to acquire a representation of the GPC regularity that is easily applied to novel contexts. Whereas some reading approaches emphasize high consistency across training items (e.g. the Word Family approach, where learners are exposed to vowel patterns across highly similar word families – CAT, BAT, HAT), the Foundations Learning System incorporates greater item diversity within training. As a learner practices a vowel GPC regularity, she encounters this regularity embedded in varying consonant contexts, in words and non-words, and in words of varying lengths. This item-level variability has been shown to boost learning of vowel GPC regularities across a wide swath of learners (Apfelbaum et al., 2013).

The Foundations System also embraces variability through adaptive item sets that respond to student performance. These item sets ensure that each regularity is encountered in multiple lexical contexts, and in the context of a varying array of competitors. Most tasks within the Foundations Learning System include easy, medium and challenge word sets, with the difficulty of the word list determined by the vowel contrasts, complexity of the consonants, the number of syllables, and the degree of challenge from the response foils. Student performance during objective pretests determines the difficulty of items they encounter when beginning a task. Depending on their performance, they may thereafter move on to a more difficult or an easier word list. The difficulty of the word lists reflects both the types of words encountered (e.g. more challenging word lists include more multisyllabic words and words with more complex consonant types) and the difficulty of the foil selections (e.g. more challenging word lists include foils that have a higher degree of overlap with the target). This adaptive placement exposes the student to a wide array of items, as well as variability in the response options seen in a trial, thus further expanding the variability of experience for the student.

Variability of training items also extends to the sets of items trained throughout different portions of the intervention. Rather than emphasizing a mastery approach, in which rules are trained in isolation until mastery is achieved, and then retired from further training, the Foundations Learning System interleaves relevant contrasts throughout numerous lessons. For example, the first Objective within online instruction of the Foundations System includes four units focused on the primary short-vowel rules of English. Within each unit, contrasts are chosen to specifically help students learn the distinctions between often difficult contrasts, and the contrasts build throughout the objective. Even after Objective 1 is complete, short vowel items continue to recur in later objectives to help train these distinctions – for example, much of Objective 2 contrasts long-vowel rules with their short-vowel counterparts to help students learn how to treat the same letters in different contexts. This interleaved approach ensures that the GPC regularities are learned in a variety of contrast contexts.

What's in the Foundations Learning System?

The Foundations Learning System was developed to embrace state-of-the-art theories from the cognitive science of learning to best serve struggling readers. In this section, we briefly summarize how the structure of the Foundations Learning System accomplishes these goals. For more comprehensive information on the structure of the Foundations System, its tasks and the items used, or to learn about the validation process used to build the assessment, view the resources on the Foundations in Learning website (www.foundations-learning.com).

The Foundations Learning System has 5 components:

1. A 20-minute online screener to quickly identify whether students have deficits in automatic word recognition skills.
2. An online diagnostic that identifies specific gaps in decoding knowledge and measures automaticity of word recognition. It typically takes three 20-minute sessions to complete and is the only scaled measure of automatic word recognition currently available.
3. Online intervention that personalizes instruction based on the principles of the Varied Practice Model.
4. Curriculum guides for teachers so they can extend, reinforce and deepen the learning provided through the online instruction.
5. Reports that enable teachers and administrators to monitor student performance as the student progresses through the System.

The integrated intervention is built specifically to enhance acquisition, application, generalization and automaticity of foundational reading skills. The online curriculum consists of 24 structured units organized around the Varied Practice Model so that students encounter the materials from multiple perspectives. The teacher-facilitated instruction provides a wealth of resources, including poems/passages, curriculum packets, and daily lesson plans to reinforce the development of automatic word recognition skills, improve reading fluency, and deepen and extend learning to new contexts that include vocabulary, comprehension, and writing.

Foundations Diagnostic ***A diagnostic assessment of decoding and automaticity.*** The goal of the Foundations Learning System is to help students acquire explicit decoding knowledge, and to train them to be able to automatically deploy this knowledge. As detailed above, these goals may demand different training approaches. In order to identify what a specific student is likely to need; the Foundations System begins with a comprehensive diagnostic assessment of students' decoding abilities and levels of automatic skill use. This assessment identifies students with different areas of need, and allows targeted training in response to these needs. Specifically, the Foundations Diagnostic measures levels of ability decoding different types of GPC regularities, such as short vowels, digraph vowels, or consonant clusters at word onset, as well as generalization of these abilities to different contexts, such as multisyllabic words and non-words. The Foundations Diagnostic also measures students' ability to use their decoding knowledge under time pressure and provides metrics for student performance in timed and untimed settings. Finally, the Diagnostic offers omnibus measures of automatic word recognition by evaluating a student's degree of decoding ability and their level of automaticity. For full description of these measures and their interpretation, see the Foundations Learning System Teacher's Guide.

The use of the Diagnostic to assess student abilities gives insight into what particular gaps a student shows in her reading ability. Teachers can use this information to tailor extension activities to specific areas of need; for example, a student who has strong decoding knowledge but poor automaticity should practice with tasks that emphasize rapid deployment of their knowledge and use of knowledge in diverse contexts, whereas a student with low decoding ability may need further explicit training in GPC regularities. Previous research using this platform has demonstrated the utility of dissociating these concepts (Roembke et al., 2019); although automaticity builds on a foundation of decoding knowledge, it also offers predictive power as an independent construct of reading ability. Subsequent implementations of the Foundations Diagnostic are given at the midpoint and completion of the Foundations Learning System, allowing educators to track student progress in these abilities. Note that and the Diagnostic is disabled in the non-conversational English-Language Learner setting of the Foundations Learning System.

Tasks to build decoding and automaticity. As detailed above, the primary goal of the Foundations Learning System is to build students' decoding knowledge and their automatic use of this knowledge. The tasks in the Foundations System are structured to directly target these goals. Tasks range from those that quite directly tap decoding knowledge (e.g. Fill in the Blank asks students to explicitly choose the letter or letters that fill in the missing part of a word) to those that demand flexible deployment of this knowledge (e.g. Find the Phrase asks students to identify an entire phrase from among a set of alternatives, requiring use of decoding knowledge in connected text; Find the Picture tasks requires students to access word meaning, requiring them to go beyond letter-sound correspondences).

A critical feature of the Foundations Learning System is the reliance on numerous tasks that use decoding abilities in diverse ways. This diversity is essential for building robust and automatic decoding skills. Training in a single context may be sufficient to build explicit awareness of phonics rules – students could be taught a rule and then complete Fill in the Blank trials until they show mastery of that rule – but their ability to readily generalize this knowledge to new circumstances may be poor. Thus the Foundations Learning System includes tasks that ask students to explicitly access specific GPC rules (e.g. Fill in the Blank); tasks that require integrating multiple GPC rules to process multi-letter sequences (e.g. Word Families); tasks that make students generate the orthographic form from an auditory signal (e.g. Spell the Word); tasks that link orthography to meaning (e.g. Find the Picture); tasks that emphasize the syllabic structure of English (e.g. Find the Syllable Breaks); and tasks that tap these skills in connected text (e.g. Find the Phrase). By completing trials in this range of tasks, students build robust memory traces for the GPC rules, which lead to effective use of their knowledge in diverse settings outside of the software.

Additionally, several aspects of the Foundations Learning System more directly target the development of automaticity. Several tasks emphasize speeded responding, through either a timer bar that delivers more points for faster responses, or a backward visual mask that covers a visually presented word after a very short interval. These tasks encourage rapid deployment of knowledge, and thus help move students from slow, explicit decoding, to more automatic use of decoding abilities. The speed of these tasks adapts to student abilities. For each objective, a pretest determines how much knowledge of the current material the student already possesses. Students that demonstrate greater struggles during this pretest receive less intense time pressure for the objective in both timer-bar and visual-masking tasks, allowing them to focus more on developing the knowledge before pushing them to rapidly deploy it. Additionally, the adaptive difficulty of the item sets presented in each task is geared to help build automaticity. Students are constantly pushed to complete trials that challenge them to deploy their knowledge in different ways, including adding non-words and multisyllabic words as they progress to item sets of greater difficulty. Providing performance-responsive challenges in the item sets ensures that students learn the various ways and contexts in which GPC rules apply.

Why focus on vowels? The Foundations Learning System focuses on training decoding knowledge for vowels because vowels present a particular challenge to students beyond first grade (McCandliss et al., 2003). Vowels are notoriously difficult in English (e.g., Hillenbrand, Getty, Clark, & Wheeler, 1995), and studies of phonological learning show protracted development of vowel categories into childhood (Havy, Bertoncini, & Nazzi, 2011). Fowler, Liberman, & Shankweiler noted that vowels carry the majority of the variable mapping difficulties in the English language, and found that early readers show a greater preponderance of vowel errors than consonant errors (Fowler, Liberman, & Shankweiler, 1977; see also, Laxon, Masterson, & Coltheart, 1991). These particular difficulties reading vowels likely arise because of less consistency in the GPC mappings for vowels (Laxon et al., 1991); learners need to develop more flexible mappings that account for more context effects and irregularities when learning vowels than when learning consonants.

To this end, the Foundations Learning System is structured around systematic training on regularities. Each unit focuses on a particular subset of vowel regularities, with the targeted vowels generally increasing in complexity from one unit to the next. Each objective includes an overarching theme of particular types of contrasts, with the goal of training students in the vowel regularities, and helping them understand the differences in usage of the vowel in different contexts. For example, the first objective presents single-letter short-vowel items (e.g. CAT, CHUNK). The second objective moves into long vowels with silent-e (e.g. LATE, FLUTE), but includes some short-vowel words to help students recognize how the same letter maps to different sounds depending on other letters in the word. The contrasts are designed to comprehensively demonstrate these context effects for vowels. This interleaving of different contrasts is critical; skilled reading requires flexibly accommodating changing contexts to apply relevant GPC knowledge – the student needs to know how a given letter or set of letters will map to sound in the current context. Additionally, later objectives show sub-regularities (e.g. –EAD often makes the short-e sound), helping students learn both the dominant regularities and the more context-dependent sub-regularities.

Although the Foundations Learning System curriculum does not directly target consonant regularities, the item sets are designed to ensure that students still receive substantial training in all regularities. First, the Foundations Diagnostic assesses consonant knowledge, including decoding abilities for consonants in different parts of the word (onset vs. offset), and consonants of different complexities (simple consonants vs. digraph and blend consonants). Second, within the Foundations Learning System, the complexity of the consonants a student encounters varies with the level of difficulty of the word list, and across units within an objective. The word list variability ensures that students with low vowel knowledge initially encounter items with limited consonant complexity; this reduces the cognitive load so they can more directly focus on the vowels. As the student improves performance, they move on to more challenging word lists, which include greater consonant complexity, helping them engage their knowledge across consonant contexts. The unit-by-unit variability ensures that all students move from items with simple consonants to those with greater complexity, again building more context-invariant mappings.

Why use a "blended" approach that includes personalized online intervention and teacher-facilitated instructions?

The Foundations Learning System aims to supplement classroom teaching that provides students with explicit decoding knowledge. However, as discussed above, knowledge of decoding without effective ability to automatically deploy it will leave a student unprepared for reading success. The individualized and personalized computer environment provides an effective way to deliver training that can help build this automaticity. Through constant monitoring of individual student ability, the online component of the Foundations Learning System is able to deliver maximally informative training items to students.

Computer-based intervention studies have proven extremely beneficial for this form of training fluent use of knowledge. Studies of Perceptual Learning Models (PLMs) in math classrooms demonstrate this value quite well (Kellman et al., 2008, 2010). In these studies, students receive typical math classroom training, while a subset of students also receives computer-based training that emphasizes the ability to rapidly and automatically deploy the knowledge from the classroom training. These computer-based training programs are PLMs: software designed to optimize content delivery to build implicit memory traces of critical material. They emphasize building automatic use of perceptual information, with this perceptual information coming to bear on the math problems. The PLMs used mirror many of the aspects of the Foundations Learning System: students complete many short trials in rapid succession, with an emphasis on variability between trials and selection of trials that best build the implicit knowledge needed for fluent use. These PLMs aim to teach students to deploy their knowledge flexibly by tapping several different mappings.

In these studies, students who completed the PLMs in addition to their classroom training showed substantial benefits over those who had classroom training alone. Critically, even when students showed strong initial knowledge of the trained material, the PLMs led to considerable improvement of the speed with which they used this knowledge, with decreases in response times of up to 50% in some conditions. The PLM training procedures helped learners develop “fluency” of their math knowledge. Kellman and colleagues liken this idea to the development of automatic skill use, with the ability to reduce cognitive load as learners deploy their knowledge (Kellman et al., 2008; Romito et al., 2016). The Foundations Learning System delivers the same form of rapid practice that can help a learner more effectively use their burgeoning decoding knowledge.

Additionally, using a computer-based intervention allows adapting to a student’s changing needs. As students’ decoding skills increase, the types of items that are most likely to benefit them will similarly shift. Proposals of keeping learners challenged, but not overwhelmed, abound in learning theory. Vygotsky’s famous theory of Zones of Proximal Development (ZPDs) argued for a dynamic window of a learner’s ability, such that as the learner grows, the types of tasks that are appropriate to continue this growth will change (Vygotsky, 1978). Similar ideas arise from concepts of desirable difficulty (Bjork & Bjork, 2011), a concept that suggests that learners benefit most from tasks that are at the boundary of their current abilities. By keeping learners challenged, such tasks support continued growth. Alternatively, practice trials that are too easy for a learner provide little opportunity for continued learning, and trials that are much too hard are unlikely to provide productive opportunities for learning and are likely to frustrate the already struggling student. A computer-based approach to practice trials allows constant monitoring to maximize trials in a student’s ZPD, as performance monitoring allows optimal selection of which trials are likely to be most helpful.

In the reading domain, this need to dynamically adjust training in response to students’ learning is pervasive. For example, learners with poor initial decoding knowledge will likely gain little from trials that demand deployment of multiple complex GPC regularities simultaneously – a student that is just coming to understand how short vowels operate is likely to be overwhelmed by multisyllabic words with many different embedded regularities and complex consonants. However, as this student becomes more practiced with the regularities, expanding the contexts and difficulty of training trials can help boost their growth. Ongoing monitoring of the specifics of students’ knowledge is challenging for a teacher; they may have many students to monitor, and performance may be highly dependent on specific decoding skills or even specific tasks. The Foundations Learning System uses allows automated monitoring of student abilities and delivers adaptive content in response to student performance.

Conclusion

The overwhelming preponderance of struggling readers in elementary, middle school and beyond makes the need for a more principled approach to intervention clear. The Foundations Learning System harnesses the modern science of learning to help remediate these chronic reading deficits in elementary and middle school children. Rather than focusing only on explicit training of the rules of reading, the Foundations Learning System software embraces research on how to strengthen implicit access to explicit knowledge. This parallel approach to teaching students to read helps create readers that both have the knowledge and possess the skills to use it effectively.

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