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THE GRAPHOGAME METHOD: THE THEORETICAL AND METHODOLOGICAL BACKGROUND OF THE TECHNOLOGY-ENHANCED LEARNING ENVIRONMENT FOR LEARNING TO READ

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Abstract: *This paper provides an overview of the GraphoGame method. Both theoretical and methodological aspects related to the method are presented. The method's guiding principles are based on the prevailing theories and experimental research findings on learning and teaching basic reading skills in alphabetic languages, especially from the point of view of a struggling reader. Because the nature of the target language and its relation to its writing system play central roles in the GraphoGame method, this approach requires the method to be flexible in order to be valid for learners of different languages and orthographies. Thus, the aim of the developed technology is to provide an appropriate reading support tool for all learners—from struggling learners to typical learners—in any language environment. We present an overview of results gained from GraphoGame intervention studies as well as challenges for the usability of the method.*

Keywords: *technology-enhanced reading support, educational game, reading skill, letter knowledge, phonology, orthography, GraphoGame.*

INTRODUCTION

In this article, we provide an overview of GraphoGame,[1] a technology-enhanced learning environment for learning to read. The aim is to shed light on the theoretical and methodological issues that guide the ongoing development and use of the technology. In addition, the impact of using GraphoGame is described, as well as the possible challenges confronting GraphoGame as a feasible tool in different contexts.

GraphoGame is a computerized learning environment for training reading skills efficiently. Initially, the impetus for developing such a support tool came from a need to help specific children identified via the Jyväskylä Longitudinal Study on Dyslexia (JLD) as struggling to learn

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basic decoding skills. For the tool to provide the most efficient support, the GraphoGame method was designed by taking into account the prevailing theories on reading development and the specific research findings of the JLD. The design, implementation, programming, and research have been conducted by a multidisciplinary team from the University of Jyväskylä and the Niilo Mäki Institute, a local nongovernmental organization specialized in research and development work on learning disabilities.

On the surface, the game appears to be like any other digital game, or rather educational game, aimed at children in the early stages of their formal education. Figure 1 shows a child playing GraphoGame. The outward appearance of the game is simple, with only a few visual elements displayed at a time, accompanied by short segments of speech. The main tasks include both time-restricted and untimed multiple-choice trials in which the player is to pair an audio segment (phoneme, syllable, word) with the appropriate visual representation (a letter or longer text segment). Mixed in with these reactive types of trials are the more active tasks of constructing written words from smaller components to match the spoken target words. The game provides immediate feedback on the player's accuracy. In the case of an inaccurate response, the game immediately guides the player to make the correct mapping, thereby teaching the player. After a short sequence of item mappings, the player is provided performance rewards in the form of game tokens, virtual stickers, and the like. The turnaround in a game is very short, providing rewards after approximately one minute of training time. Some elements in the game can be manipulated by the player, thus giving the player a sense of choice, for example, choice involving the outward appearance of the game characters, the selection of tasks to play next, or the direction the game character moves on a map. One feature

Figure 1. A child, wearing headphones, plays GraphoGame on a laptop computer, one of many devices that can host GraphoGame.

supporting the maintenance of engagement is that the game adapts to the player's learning, providing positive feedback while progressing to increasingly complex levels of reading acquisition. Appropriate algorithms were incorporated to keep the learner interested in continuing to play. In short, the game provides learning opportunities in connecting speech elements to written elements in an efficient game-like environment.

Beyond the simple surface of the game, a rather complex set of algorithmic systems and principles operate. Before introducing these guiding principles, we will review some underlying theoretical issues and research findings regarding reading development, which will pave the way to explaining the principles on which the GraphoGame method is based.

BASIC ASPECTS OF LEARNING TO READ

To learn to read written texts, one needs to understand how the visual symbols correspond to spoken language. This task differs considerably from the task of acquiring spoken language skills. Infants acquire spoken language skills from their natural surroundings. They learn by observing, in social situations, those who use spoken language to convey meanings. In general, infant-directed expressions typically are clearly enunciated (in "Motherese") in close social contact, accompanied by eye contact, facial expressions (e.g., smiling), and physical gestures (e.g., pointing). The close proximity of the face provides the opportunity to observe the movements of the mouth while simultaneously hearing the vocal expressions accompanying the other media of communicating. At the same time infants typically are exposed to other registers of fluent speakers in the vicinity who provide the overall context of the spoken language with its many features (stress patterns, intonations, rhythms, frequently used sound qualities, etc.). Often infant-directed expressions involve few words, are repeated frequently, and begin with concrete relations to the environment and move toward more abstract and complex expressions over time.

The typically developed, highly attuned perceptual system provides a natural starting point for learning to process surrounding sounds in general. Quickly the perceptual system focuses toward meaningful spoken language expressions and, with the accumulating experience, observations start to focus on the points in the spoken language that seem to maximally carry meanings. Also, infants tune into features that are meaningful for differentiating expressions from each other. At the same time infants themselves spontaneously start to experiment with producing speech sounds from which they will receive immediate feedback in different forms (mainly auditory and tactile) as well as feedback from the people around them.

Learning to speak happens naturally by children through their observing and participating in shared communicative situations with other speakers. Broadly speaking, by the age of 5 or 6, children have mastered all the basic tools of spoken language both to be understood by others and to understand other speakers of their native language. They have developed a relatively wide vocabulary, mastered the syntactical relations of their language, and attained a fully developed phonological system (see, e.g., Bates & Goodman, 1999; James, 1990). Typically children have encountered written language in some form, for example, in books read to them and/or through exposure to written language in their surroundings (e.g., in signs, magazines, printed advertisements, TV, etc.) well before age 5. However, from around this age onwards, they are guided actively to take notice of the visual symbols of written language.

The foundation for cracking the written code relies heavily on the mastery of spoken language. However, some general but fundamental differences between spoken and written language may affect one's learning to read and write, regardless of the mastery level of the spoken language for communicational purposes. First, spoken language in its informal mode typically has many varieties (e.g., regional dialects, idiosyncrasies), with words, syntactical forms, and pronunciations that can differ considerably from the relatively formal and standard forms expressed in the written language. Thus, children less exposed to the type of language used in a written format will have to learn this new code and, at the same time, understand how to modify their spoken expressions for spelling and in forming new mental representations of words. Second, spoken language is basically composed of acoustical streams that often do not have clear pauses between words, whereas, in written language, words are distinctly separated by empty spaces. Even within the words themselves, the different components (e.g., letters) are clearly separated.

The aforementioned differences between the two language modes can have an effect on spelling but, more important, it is vital for the learner to understand that the acoustical stream is not made up of individual speech sounds appearing in an orderly sequence but must be actively analyzed and segmented into separate items in order to make sense of how the two modes of communication are connected. This task is cognitively demanding and, subsequently, some learners will have difficulty in managing this task. In written language, letters do not overlap: They are distinct visual units, sequentially placed one after another. Speech, on the other hand, is a complex multilayered signal in which sounds are interwoven to each other. In other words, due to coarticulation, the context (i.e., the neighboring sounds) affects the way a sound can be produced and, therefore, affects how it sounds. In fact, every time a speech sound is produced, multiple characteristics that can affect the sound quality, including prosody beyond the sound itself (i.e., suprasegmental features), make this sound unique. Figure 2 shows waveform and spectrograph representations of a spoken expression that highlights the stream-like character of the speech signal.

For conceptualizing and managing the variation in the actual realizations of speech sounds, the abstract concept phoneme[2] is often used the same way as the concept grapheme[3] is used for written language (Shankweiler & Lundquist, 1992). The abstractions in phonemes facilitate the focus on distinguishing speech sound features that affect the meaning within the context that the sounds appear and that usually are represented in the written language form. Therefore, the same phoneme can represent a relatively wide range of actual speech sounds. At this point it should be noted that typically only a limited number of features related to spectral information of speech signal are represented in written forms, thus leaving, for instance, a variety of suprasegmental features of speech (e.g., stress, duration, pitch) unmarked in the written format. People create mental representations of speech sounds for facilitating organization, categorization, and accessing them. For learning to read, these representations play a crucial role in order for learners to be able to organize and categorize the huge range of variations of speech features. We will return to the concept of representations when reviewing some theoretical issues of reading development.

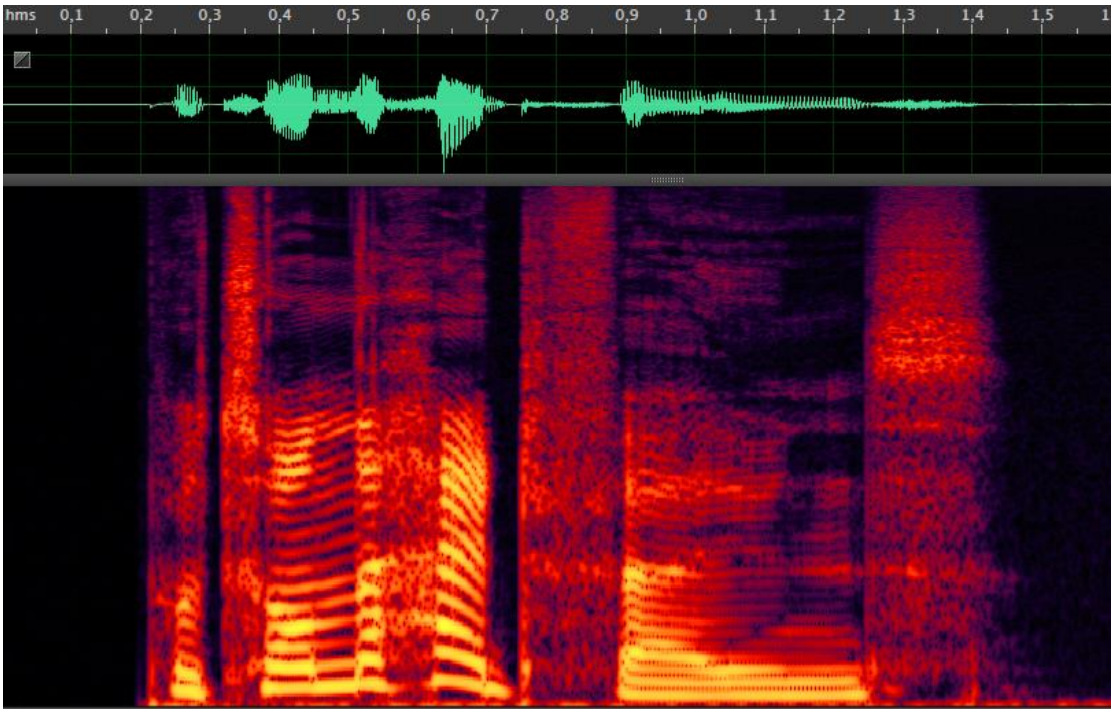

Figure 2. Speech wave and spectrogram representations of the naturally produced utterance "Put on the headphones." This image illustrates the nature of spoken language, which is stream-like and without clear gaps between words. Note that individual phonemes are not clearly distinguishable.

Whereas mastery of spoken language skills develops through conveying meanings, the first step in learning to read, at least in alphabetic languages,[4] needs to be approached from the opposite direction—from connecting small meaningless items (e.g., letters) in order to make up meaningful chunks (i.e., a combination of words). To understand how spoken words can be segmented into something as small as phonemes, which should correspond to written letters, a child is required to make a conscious effort to metalinguistically approach the already-mastered spoken language mode. Researchers (e.g., Bradley & Bryant, 1991; Duncan, 2010) argued that children do not necessarily become explicitly aware of a segment size as small as the phoneme before starting to learn to read. This is based on observations indicating that a phoneme is not psycholinguistically the most accessible segment size of spoken language. Instead children often prioritize, in their language games and songs, larger segments such as syllables and rhymes, which seem to be rather easily accessible and useful in the early development of spoken language communication. As a child's vocabulary expands, particularly when an increasing number of words are very similar in form, the child also might become aware of phoneme-size features of speech in order to be successful in communication. In fact, Metsala and Walley (1998) argued that the typically rapid vocabulary expansion forces children to pay attention to smaller segment sizes of spoken expressions in order to place the new words into their existing lexical systems.

The mastery of spoken language in typical social contacts is acquired through natural communication, effortlessly, through concentrating on conveying meaning without needing to pay any specific attention to the actual productions. Learning to read and write, on the other hand, is a skill that requires deliberate effort and training, and the way written language maps to

spoken language needs to be specifically taught. Cognitively, the learner needs to have intellectually developed to the point in which abstract and rather demanding, memory-taxing operations can be performed in order to learn to crack the written code. In the upcoming section, we review prevailing theoretical aspects on reading development supported by research findings.

THEORETICAL ISSUES AND RESEARCH FINDINGS REGARDING READING DEVELOPMENT

The Effect of the Orthography in Learning

In simple terms, learning to decode written text in any type of language entails discovering what the written symbols represent. A learner must be shown the principles of how a certain written symbol (e.g., a letter) connects to something that the learner already knows (i.e., a speech sound). In transparent orthographies (e.g., Finnish, Italian, Greek, the Bantu languages), where in principle one letter connects to only one specific speech sound, cracking the code can be considered easy, straightforward, not extensively taxing on memory and, as such, a relatively quick skill to learn. Once the learner has memorized the connections between the letters of the alphabet and the unique phonemes connected to them, the learner will be able to decode and pronounce all words in that language, as well as invented, meaningless words (pseudowords). After only a few months (sometimes just weeks or even days) of formal training, typically developing children who have been exposed to letters prior to school (e.g., in learning to write their names) have mastered this basic technical reading skill. In less transparent (opaque) orthographies, single letters are connected less consistently to specific sounds but rather the connections depend on larger linguistic context (e.g., the surrounding letters or the letter's position in a word). Therefore, mastering the alphabetic principle provides only a part of the key for decoding. A substantial part of learning requires experience with the specific written formats, including irregular spellings. This may require learners to practice the word formats by heart or to connect larger strings of letters to specific sounds. For example, in English no single letter always corresponds consistently to the very same sound. However, larger chunks are much more consistently connected to specific sounds in English (e.g., rimes[5]), and knowledge of these connections facilitates reading acquisition (Ziegler & Goswami, 2005). Therefore, children learning to read in English need ongoing exposure to different types of contexts to understand how letters or combinations of letters represent different speech sounds.

As can be seen, learning to read in an opaque orthography (e.g., English, French, Hebrew; see, e.g., Katz & Frost, 1992) is clearly a more complex task than learning to read in a transparent orthography. One main challenge at the beginning of reading training is how to segment the speech flow in such a way so that a spoken unit could be connected to a written unit, which is the core of learning to read. It is not surprising, then, that cross-linguistic studies have provided evidence that it takes considerably more time to learn to decode words in languages with opaque orthographies (i.e., several years instead of several months; Seymour, Aro, & Erskine, 2003). Therefore, the nature of the orthography plays a significant part in the means by which reading is learned. This leads to our upcoming brief description on some prevailing methods of instruction, which vary according to the target orthography.

Methods of Instruction

Research has shown that for transparent orthographies, meaning those with consistent connections between letters and sounds, it makes sense to concentrate on teaching exactly these connections (Holopainen, Ahonen, & Lyytinen, 2002; see also Landerl, 2000, for a review see Perfetti, Beck, Bell, & Hughes, 1987). For typically developing readers, this provides a simple and quick way to learn to decode. Instructional methods vary in the extent to which these connections are utilized.

The instructional methods using phonics can be divided into two main categories: analytical and synthetic. The analytical phonics method uses an approach in which the quality of the speech sounds are referred to in the context of words. Learners are tasked with analyzing the similarities and differences between words in terms of the sounds they contain. They need to infer from, for example, the spoken words *pet* and *pat*, that the words have similar sounds apart from the sound in the middle, which alone changes the meaning of the whole word. In the method using the synthetic phonics approach, speech sounds are introduced separately before starting to combine sounds into larger chunks that can carry meaning. The idea is to teach the sound-based tools first, which can then be utilized for decoding anything that includes these letter sounds, without taking into account the context in which they occur.

The crux of the instructional methods using either of these phonics approaches lies in the employed sounds. Basically, the choice is made between using either the phonemes or names given to the letters. Using letter names leads to using analytical and deductive approaches because languages vary in the extent to which the given names of letters include the actual phoneme within its phonetic representation. In languages with transparent orthographies, the sounds of letters are typically represented quite well via their names, with an additional vowel or consonant sound, depending on the letter. As an example, the Finnish name of the letter *h* is pronounced [ho:],[6] the consonantal part of which solely forms the phoneme sound [h] for the letter. Thus, children would have a chance to infer that this particular part of the sound in the name matches its phoneme /h/. In English, the name of the letter *h* is pronounced /eɪtʃ/, which does not contain the typical glottal fricative /h/ that is often represented by the letter *h*. By pronouncing the name of the letter *h* alone, the specific phoneme sound is impossible to deduce. These examples underscore that the pronounced letter names can be useful for deducing the letter sounds, but this is not always possible in the case of nontransparent orthographies such as English, where none of the letters represent the same sound in all contexts.

Using the letter names might also lead to problems in reading and writing. Sometimes struggling learners make mistakes by relying on the letter names. For instance, they can make mistakes by stringing together the letter names when trying to read an unfamiliar word (e.g., seeing the letters for the word *stop*, /es//ti://ou//pi:/, and pronouncing /esti:oupi:/), an error avoided when stringing together phoneme sounds. Thus, it makes sense for at least transparent orthographies to use phoneme sounds in instruction—easy with vowels but more difficult with some consonants. Also, the use of appropriately chosen syllables, where different vowels are connected to the consonant, can be very helpful for introducing specific consonants to early learners. This is because it is impossible to audibly produce, for example, a stop consonant (e.g., [p]) without a release of the consonant into some vowel sound. When a stop sound or any other type of consonant sound is the target sound, the vowel part is produced in as insignificant

manner as possible, which usually is realized as short schwa sound. This can be challenging for anyone without specific phonetic training.

Although using letter names for teaching decoding can cause particular problems, a learner's letter knowledge (whether letter names and/or letter sounds) has been found powerful as a predictor of reading acquisition within the first years of formal education (e.g., Lyytinen et al., 2008). In order to memorize and utilize the more or less systematic relationships of such abstract meaningless units (letters and how they are connected to speech sounds) that form the core element of the written code (at least in alphabetic languages), learners need to have such tools to rely on in progressing in their technical reading ability.

Apart from the phonics approach, especially in the case of opaque orthographies, larger chunks than letters are used in instruction (Goswami, 1986, 1988; Walton, Walton, & Felton, 2001). One such method focuses on decoding by analogy. It is expected that learners can use their knowledge of the previously learned orthographical units to work out how unfamiliar words are read and spelled. For example, in learning to read in English, the frequent spelling patterns of phonological rime "neighborhood families" are highlighted (e.g., *sit, pit, wit* or *rime, lime, time*) to focus attention to the orthographical systems of the consistent language units, which, in the case of more opaque orthographies, are units larger than single letters. It should be noted that in the analogical method, phonics is employed as well.

The only instructional approach that does not focus on the sublexical units is the sight word (i.e., whole word) method. The learner's task in this method is to learn by heart the full orthographical sequence (i.e., a word, or words in short sentences), which places the focus on the meaning of the words. At first glance, this method might seem to be useful and a quick way of making learners read for meaning. However, research has demonstrated that exclusively following this instructional approach places high demands on the memory, and learning new words in new sentences is not facilitated (Ehri, 2005). Noteworthy, however, is that in English, for example, successfully sounding out the first sounds of some words is impossible without seeing the whole written word. As a result, a certain limited number of words have to be learned by sight and some can work as the initial introduction to reading English. But in general, reading and spelling accuracy does not develop efficiently using this method alone.

Further comment is in order in light of our own experience. We have found that some foreign language learners, at the early stage at least, learn to read English by employing a grapheme–phoneme correspondence strategy similar to how they learned to read their first language with a possibly more transparent orthography. They might not have much knowledge on how to pronounce the English words, but they can read and spell them with relative ease. The difference between native speakers of English and these foreign language learners is in the pronunciation of the decoded words: The English words pronounced by foreign language learners might very well be unrecognizable to native speakers. This is an example of decoding skills without any connection to the phonology or even semantics of the target language. Thus, the exposure to the orthographical forms and whole words prior to developing phonological skills might not be a hindrance for developing good reading skills in English for some foreign language learners who already have reading skills in another language. Yet, only when the phonological system of the foreign language learners develops to resemble that of native speakers do these foreign language learners start experiencing interferences from their developed phonological skills, so much so that, for example, their spelling skills in English deteriorate at least slightly (especially with homophones).

In summary, for languages with transparent orthographies, the synthetic phonics method seems to be the most efficient. For languages with less transparent orthographies, an approach that takes into account the psycholinguistic grain size (see Ziegler & Goswami, 2005) of the specific target language and that uses sublexical information for teaching (often mixing different phonics methods) is the most successful way for teaching technical reading skills.

Learning to read does not happen all at once. The tools for decoding and for spelling need to be learned first, after which further training is needed in order for these skills to be automatized. One is ready for the effortless and quick reading of words (i.e., is literate) only after a substantial amount of practice. When reading is automatized, the cognitive load associated with the reading process is minimized, leaving resources for reaching the ultimate aim of reading—comprehension. Due to the main focus of this article, we limit our review on the technical stage of reading development to focus on the apparent variations in learning development that are independent of the instructional method employed.

Learners with Varying Abilities in Learning to Read

Reading skills need to be learned and are not just effortlessly acquired, as is the case with spoken language skills. Fortunately, most learners will gain sufficient reading skills with practice if they are provided with adequate learning opportunities (i.e., appropriate instruction, practice opportunities with reading material, etc.), have no significant sensory deficits, and their cognitive capacity is not severely compromised. Unfortunately, some children, despite having the aforementioned prerequisites, find reading extremely difficult. They have a developmental disorder, dyslexia, related specifically to the development of reading skills. Research has shown that more than 20% of early readers are struggling (e.g., Scarborough, 2009). A small portion of children can be defined as suffering from dyslexia, a severe hindrance to even optimal training in reading (Snowling, 2000). Typically individuals with dyslexia make a significant number of mistakes in reading and spelling, which hinders progress toward fluency. The types of difficulty that individuals with dyslexia experience depend on the orthography of the target language. Whereas those learning to read in a language with an opaque, inconsistently behaving orthography have both accuracy and fluency problems, those learning a transparent orthography typically manage to learn, possibly due to the straightforwardness of the grapheme–phoneme connections, although their reading tends to remain significantly slow and effortful.

Although this developmental condition has been investigated widely over the years (e.g., Orton, 1937; Snowling, 2000; Stanovich, 1988), researchers have not yet come to an agreement on the root of the matter. Research cannot identify a single cause of the condition. Instead, several competing theories have been posited on the possible causes. One prevailing theory, supported with experimental evidence across languages, is that dyslexia has its roots in cognitive difficulties to process phonological features, which is manifested in the individual having difficulty processing written language (e.g., Stanovich, 1988, Ziegler, 2006). In practice this means that individuals with dyslexia have difficulties to various extents with tasks that require the ability to manipulate speech sounds, even in tasks not involving written language, whereas typically developing children have no such problems. The reasons for the phonological deficit are not clear. Researchers have speculated that the quality of mental representations (i.e., poorly specified or indistinct) and/or the quality of access to these representations might explain the link between phonological awareness and reading skills (e.g., Elbro, Borstøm, &

Petersen, 1998; Elbro, Nielsen, & Petersen, 1994; Fowler, 1991). It could be that the nonsegmental, multilayered nature of the speech signal, as we described above, makes it difficult for individuals with dyslexia to distinguish the features that can be reduced into something that is an approximation of the actual sounds produced and/or perceived. Whereas some evidence indicates that some individuals with dyslexia actually perceive smaller differences in sounds and speech sounds than typical reading individuals (Bogliotti, Serniclaes, Messaoud-Galusi, & Sprenger-Charolles, 2008**),** other studies have shown that these challenged readers require greater differences between sounds in order to categorize them (e.g., Richardson, Leppänen, Leiwo, & Lyytinen, 2003). In fact, a deficit in any of the basic acoustical features (i.e., spectral, temporal, or amplitude) has been connected to poor reading skills to some extent, with the temporal deficit being most frequently related to dyslexia. A unifying feature of the studies on auditory perception (of both speech and nonspeech sounds) is that only some, but not all, individuals with dyslexia performed significantly differently from typically developing readers. Thus, differences in auditory perception do not offer a single causal explanation for the conditions. It should be noted also that, apart from phonology, there are studies on other levels of linguistic analysis (mainly on morphology and syntax) in connection with poor reading skills, but the research thus far is relatively scarce and findings too limited for drawing conclusions.

A significant number of people struggle with reading all through their lives, which significantly impacts their quality of life. Much of formal education is based on written language, as is the case with significant amounts of information conveyed outside education. If children, from the start of their educational careers, feel they are not coping with the core element of learning as well as their typically developing peers, they can easily become discouraged and frustrated, which might lead to, for example, avoidance behavior and low self-esteem issues. Although struggling readers would benefit from having access to appropriate and usually long-lasting professional support for improving reading skills after they have been struggling during the first years at school, early intervention programs for alleviating or even preventing dyslexia are, however, considered to be the most beneficial approach for providing efficient support. Therefore, to enable early intervention, researchers have begun looking for indicators of dyslexia in the period before children normally receive instruction in reading. These kinds of investigations have been made possible due to the convincing evidence that dyslexia is genetic (for a review, see Wood & Grigorenko, 2001).

The evidence that dyslexia runs in families also was the premise for the Jyväskylä Longitudinal Study on Dyslexia (JLD), in which parents and/or immediate family members with dyslexia, and their children in particular, have been studied for 2 decades now. In the JLD, the investigations started from the birth of infants to parents with and without dyslexia. As a result of our multidisciplinary investigations, various markers of dyslexia have been observed from the early development of these children, starting from the first statistically reliable sign recorded at the age of 3–5 days (e.g., Guttorm, Leppänen, Hämäläinen, Eklund, & Lyytinen, 2010). Apart from the auditory perceptual atypicalities and difficulties in phonological skills, the JLD investigations provide strong evidence that letter–sound knowledge at the age of 5 (2 years prior to children entering school in Finland) is the single strongest predictor of reading acquisition at the early stages of education in virtually all cases (e.g., Lyytinen et al., 2008). Similar evidence has been gained from many studies across languages in connection with poor reading skills (e.g., Scarborough, 2009). Thus, assessing letter knowledge skills prior to school entry provides a

simple and solid basis for predicting the reading outcome of children. Through a dynamic assessment of the child's knowledge of letter names, assessors can gain objective evidence of the child's ability to connect graphemes and corresponding sounds. With this information, extra support can then be directed toward those children who are likely to suffer from poor reading skills even before they encounter problems with reading. This finding is the core motivation for developing the GraphoGame method, the features of which we will describe next.

BASIC FEATURES OF THE GRAPHOGAME METHOD

The GraphoGame method was designed to facilitate children learning to connect written language segments with the corresponding speech sounds. Initially, the game was developed for children learning to read in the Finnish language and, more specifically, for those who showed early signs of reading difficulty at the end of kindergarten (typically 6.5 to 7 years of age), just months before entering the first grade. The method is meant to be used as a support tool for learning: It is not a replacement of teaching but rather provides preventive help.

The design of the training content used in the GraphoGame method is based on research findings. For languages with transparent orthographies, the nature of the training materials is straightforward. Because each letter represents a specific phoneme and vice versa, the game starts with introducing these correspondences. Using the synthetic phonics approach, the game starts by presenting phonetically and visually distinct grapheme–phoneme correspondences as a group (e.g., *a*, *s*, *t*) after which it moves to present correspondences that are phonetically less distinguishable (e.g., *m*, *n*, *l*). Next it introduces psycholinguistically relevant larger sublexical units of the target language, such as syllables or rimes, before introducing words. The expectation is that word decoding is basically achieved by knowing what sound the individual letters represent and simply combining them in an order to arrive at the written words. More interesting, we have heard that typical learners of transparent orthographies often remember the specific day they learned to read, that is, conceived their own mental system of connecting the sounds of subsequent letters while attending to the meaning of a text.

For languages with less transparent orthographies, the approach depends on the type of connections the written units have with spoken language units. For example, both synthetic and analytical phonics approaches have been used in the GraphoGame in English (Kyle, Kujala, Richardson, Lyytinen, & Goswami, 2013). In using this mixed-method instructional approach, the sublexical written language elements (rimes) that most consistently and frequently represent specific sounds and combination of sounds are utilized. For the GraphoGame English Rime version, the learning content is structured into streams with several levels that explicitly instruct learners on orthographic rime units (see details in Kyle et al., 2013). First, the game introduces the specific grapheme–phoneme connections that can be combined to form specific rhyming word families. The game immediately allows the learner to play with rime units, thus providing opportunities to reinforce the newly acquired grapheme–phoneme connection skills. This, in turn, facilitates the player's recognition of psycholinguistically relevant reading and spelling units in English. The last phase in this stream is to play with other words that contain the rime units learned in the previous levels. The order in which the rime units are introduced is based on the phonological neighborhood density of the rime units, in line with the database constructed by De Cara and Goswami (2002). Also the frequency and consistency of these rime

units are taken into account in the presentation order. The selection of high-density neighborhood rime units begins with the most frequent and consistent items and moves toward those in low-density rime neighborhoods.

The GraphoGame method takes into account the way in which specific written and speech sound units are systematically connected in a specific orthography. In addition to phonologically based connections, morphology and semantics can play a decisive role in the game design for orthographies in which these particular linguistic aspects are important (e.g., in French and Mandarin Chinese). Thus, the GraphoGame method's approach is to provide training with the most functional sublexical units of the specific orthography. This entails that training is focused on the most frequently and consistently used connections between the smallest distinguishable parts of the written and spoken language for learning the mappings of the particular orthography to the spoken language form. Through this process, the method aims to provide learners the opportunity to use sublexical units as building blocks for reading and spelling words. In addition, although the game usually offers implicit learning opportunities, some game versions also provide, to varying extent, some explicit instructions and demonstrations on particular issues, such as specific orthographical rules and irregularities that should be learned.

The produced sounds presented in the GraphoGame play an important role in the method. Because struggling readers have been found to differ in their speech perception skills from the typically developing readers, specific attention has been paid to the quality of the sounds used in the game. In the GraphoGame method, only naturally spoken sounds are employed. For achieving a high quality for the sounds, only recorded speech by trained native speakers is used. In addition, recordings are done in professional recording studios, which provide noise-free sound quality. The speakers are instructed to use a specific standardized pronunciation style representative of the language in question. Although the sounds are enunciated clearly, the sounds should illustrate natural characteristics of each specific target language, such as the typical speech rhythm, pitch, and intonation of the language. In addition, the speakers are instructed to try to control the durational and spectral characteristics of the productions. Special attention is paid to the way individual sounds are produced so that the majority of the produced sounds demonstrate the distinguishing characteristics of the target sounds. Thus, for identification reasons in some consonantal sounds, for example, the necessary formant transition to the accompanying vowel is also present in the sound. The reason for the specific requirements for the quality of the sounds is to provide learners opportunities to construct good, distinct mental representations of speech sounds. This is important because it has been argued that dyslexia involves fuzzy, indistinct phonological representations (e.g., Elbro, 1998).

The nature of the presented speech sounds is also taken into consideration in determining the order in which they are presented in the game. Sounds that clearly differ acoustically from each other are presented first. Once these have been learned, acoustically similar sounds are presented within the same game level. In this way, learners are guided to pay attention to the specific distinguishing characteristics of sounds. This is believed to offer learners the opportunity to reconstruct and refine the way they identify speech sounds. Also, the use of headphones is vital when playing the game: Because of the brevity and quality of the single speech sounds, headsets allow learners to hear the sounds properly. Additionally, several speakers' voices can be utilized in the game, providing a further opportunity for learners to develop their speech sound categorization skills. This is important because the speech

categorization skills have been showed to be different in struggling readers (e.g., Steffens, Eilers, Gross-Glenn, & Jallad, 1992).

The intention with the multimodal (i.e., visual and auditory) stimuli presentation is to provide support for constructing clear mental representations of specific features of both speech and written stimuli independently. At the same time, the method provides immediate connection between the two stimuli types, which in turn facilitate reading skills development. The method provides plenty of repetitions of exactly the same stimuli in different contexts (i.e., visually, auditorily), thus providing learners the necessary opportunities to build the representations and learn concretely the connections needed at the first stages of the learning-to-read process. Outside this kind of technological learning environment, this number/frequency and quality stability of repeated stimuli is not feasible.

One key feature of the GraphoGame method is that the game progression varies according to a learner's current skills. The game continually logs the player's performance with both accuracy and time measures. For the different types of game versions, several specially designed adaptation mechanisms are employed. The unifying feature for the various adaptation systems is that, according to the performance in each particular trial, the game is able to provide learning material in subsequent trials or levels aimed at the player achieving about 80% correct responses on each level. This simultaneously provides both sufficient challenge and ample opportunity for success, which together facilitate engagement in the game. Moreover, similar game levels are presented in several graphically different settings in order to keep players interested in repeating the same type of activity hundreds of times. In this way, each learner is exposed to the same connections with sufficient repetition for learning to occur.

One key principle in the GraphoGame method is to provide immediate feedback for each action. Typically, a player is presented a sound and must connect it to its written counterpart from a set of alternatives. Immediately upon the selection, the player is presented with either positive auditory and visual feedback on the correct response, or visually for an incorrect selection. Typically, the incorrect selection is displayed in red, whereas the correct response is highlighted in green. The significant point is that, following an incorrect response, the player must actively demonstrate learning by selecting the correct response before moving on to the next trial. In this way, the method emphasizes the correct correspondences of the spoken and written forms. By highlighting only positive feedback, the method aims to not discourage the learner by paralleling any negative feedback that the learner might be receiving in other learning contexts. Another way of accessing feedback on progression in the game, apart from the immediate feedback within the training levels, involves the game-provided static assessment levels of basic reading-related skills. Typically provided at various points in the training, these tasks assess the learner's letter–sound knowledge and word and pseudoword recognition, as well as sentence processing. The players see their numeric progress at the end of each completed task; these assessment tasks provide an additional means for the teachers and parents to gain information on learners' progress.

The above provides the general framework within which the GraphoGame method operates. Due to the linguistic and orthographic constraints and the varying background characteristics and starting skill levels of learners, dozens of GraphoGame versions have been developed. This prompts us to next summarize the effect of training with GraphoGame revealed in several experimental studies.

AN OVERVIEW ON THE IMPACT OF THE GRAPHOGAME METHOD

Several efficacy studies have been conducted on the GraphoGame method. Here we briefly review the main findings of some of the controlled experimental investigations that focus on supporting the first steps of reading development. Some GraphoGame intervention studies showing its effectiveness have focused also on fluency training (e.g., Heikkilä, Aro, Närhi, Westerholm, & Ahonen, 2013; Huemer, Landerl, Aro, & Lyytinen, 2008). However, because these fall outside the focus of this paper (basic decoding skills), we will not review them here.

Several experimental intervention studies have been conducted in Finland, whose language (Finnish) is one of the most transparent orthographies. Mönkkönen et al. (2014) studied kindergarten children just before they entered school (avg. 6.5-year-olds) in a cross-over intervention design in which about half of them played GraphoGame Reading (n = 58) and others (n = 52) played the GraphoGame Math (the same game but with math content) as a control game for 6 weeks each, for an average of 3.5 hours total per child per game. In addition, children who did not participate in any intervention (n = 41) were included in the study as nonplaying controls. All the children were prereaders whose letter knowledge could be categorized as poor, meaning they knew fewer than 12 letter–sound connections or letter names at the preintervention stage. The data showed that children who played GraphoGame Reading improved their letter knowledge and pseudoword reading significantly in comparison to both the GraphoGame Math and the nonplaying control groups. Saine, Lerkkanen, Ahonen, Tolvanen, & Lyytinen (2010) conducted a longitudinal intervention study using the GraphoGame method with native speakers of Finnish. Two cohorts of children from four schools from the same district (N = 166) were followed. At the start of the study, the participants were first graders (7 years of age); they were followed until the first term of Grade 3. The participants were divided into three groups. One group (n = 25) comprised children who needed extra support in decoding skills according to their performance on several reading-related assessment tasks during the first weeks of school. They received regular remedial support in groups of five for 45 minutes, four times a week, for 28 weeks beginning at the 7th week of school. The second group (n = 25) was otherwise similar but they received GraphoGame training during the first 15 minutes of their remedial lessons (i.e., the time used for playing the game replaced the face-to-face remedial instruction that these children were receiving). All the children in these two randomly assigned groups represented the lowest 30% achieving students in the assessment tests. The third group of children (n =116) were the classmates of the children in the reading remedial intervention groups. Their reading assessment scores were good enough at the beginning of the school that they did not need any extra support for improving decoding skills. The results of this longitudinal study indicated that at-risk children who received the GraphoGame intervention improved their readings skills to a level similar to their nonintervention mainstream peers and were significantly better readers on most measures than the children of the group receiving only traditional remedial teaching. As can be seen from the results of these two studies, the GraphoGame method brings significant positive results for struggling readers learning to decode in a transparent orthography.

The encouraging results from the Finnish studies have been extended to other language environments with similarly transparent orthographies. In the richly diverse language environment of the Sub-Saharan African country of Zambia, the first language of residents is typically one of the several local Bantu languages. The alphabetic orthographies of the Bantu

languages are almost as transparent as that of the Finnish language—symmetrically transparent in both reading and writing directions the result of the languages only recently being committed to script. No changes to the spoken languages have taken place since the written language forms for the target languages were developed, and the missionary-developed orthographies were based on a Latin model, similar to Finnish. Thus, logically, we could expect the GraphoGame method to be as efficient for learning to read Bantu languages as it has been demonstrated to be in the Finnish environment. However, whereas the language environment of the Finnish speaking children in Finland is extremely homogenous (approx. 90% of the population speaks Finnish as their mother tongue; Tilastokeskus, 2014), the language situation in Zambian schools is much more diverse. Throughout the country, several different Bantu languages are spoken, as well as English, the lingua franca of the nation. Most children, however, do not speak English and may not have been exposed to it in their surroundings before they enter school. The recently-implemented Zambian language policy followed in education specifies that although initial teaching in the first four grades should be provided in one of the seven official local Bantu languages, English will be used from the fifth grade onwards as the language of instruction (Use of Local Languages, 2013).[7] This diverse language situation alone, apart from the fact that languages with both transparent and nontransparent orthographies are being taught in schools, makes this learning environment significantly different from that of Finland. A second very important difference is that most Zambian children get little or no exposure to written texts (in any language) in their home environment before starting school. Thus, due to the obvious differences between the learning environments in Finland and Zambia, several intervention studies have been conducted in ciNyanja, one local Zambian language with a transparent orthography, to see whether the GraphoGame method would be an efficient training tool in such a diverse language environment. The review by Ojanen, Kujala, Richardson, & Lyytinen (2013) shows that indeed significant improvement in the assessed spelling skills and orthographic knowledge was evident in the first- to fourth-grade ciNyanja-speaking children after approximately 2 hours of training time over a 4-week period. A more recent result from Jere-Folotiya et al. (in press) documents how the effects of the GraphoGame method are reliable only if the teachers receive appropriate information on synthetic phonetics in the target language in advance of the intervention.

The GraphoGame method also has been applied to languages with nontransparent grapheme–phoneme correspondence. Kyle et al. (2013) conducted a controlled experimental intervention study with English-speaking second graders (6- to 7-year-olds) in the United Kingdom. In this study, a specific interest was in the training content used in the GraphoGame method. Two game versions, GraphoGame Rime and GraphoGame Phoneme, were developed for this purpose according to two different theoretical approaches on reading instruction in English. The data show that after about 11 hours of training over a 12–week period, children who played either version of the GraphoGame improved their decoding skills significantly in comparison to a nonplaying control group. However, of the two approaches, training with GraphoGame Rime produced more significant improvements in comparison to GraphoGame Phoneme. This study indicates that technology-enhanced training method such as GraphoGame can be an efficient tool for training basic reading skills in languages with nontransparent orthographies.

Apart from significant changes in reading behavior, some studies indicate that the effects on training with the GraphoGame method also can be seen in brain physiology. Brem et al.

(2010) conducted an intervention study in Switzerland of German-speaking kindergarten children with the same research design as Mönkkönen et al. (2014), described above. The nonreading children (*N* = 32; 6–7 years of age) played the game, on average, 3.5 hours in total over an 8-week period. The data on the behavioral assessments indicated that these children's letter–sound correspondences in a slightly less transparent orthography than Finnish and ciNyanja improved significantly after playing GraphoGame. More interesting, the functional magnetic resonance imaging (fMRI) data on some of these children (*n* = 16) show that learning outcomes indicated by the behavioral data had a significant effect on a neural level. The posterior areas of the brain that specialize in visual processing, including written language, became significantly activated while merely training with letter–sound correspondences. In addition, the electroencephalography (EEG) recordings revealed that in only a quarter of a second after visual presentation of either written words or symbol strings (no letter shapes), the learners' brains could differentiate these two types of visual symbols. Thus, these results indicated that training such as that provided by the GraphoGame method has a significant neural-level effect on written language processing. Similar, neural-level evidence is apparent on the Finnish kindergarten children participating in the Mönkkönen et al. (2014) study (see also Guttorm, Alho-Näveri, Richardson, & Lyytinen, 2011).

This has been a very brief overview of some of the controlled experimental studies in which the GraphoGame method has been utilized. Because one key principle behind developing the GraphoGame method is to provide an evidence-based support tool for decoding skills, new language versions of GraphoGame are being developed for different types of orthographies for use in various cultural environments. In addition, more large-scale studies are needed for investigating the efficiency and usability of the GraphoGame method in terms of, for instance, learning nonalphabetic languages, languages with nontransparent orthographies, and tonal languages, as well as second languages. In the final section of the paper, we provide a summary on some of the most significant challenges facing the GraphoGame method.

CHALLENGES OF THE GRAPHOGAME METHOD AND WAYS TO OVERCOME THEM

Although the GraphoGame method shows promise as an effective support tool for developing and improving decoding skills, several theoretical, methodological, technological, and environmental challenges may hinder, to some extent, the usability and feasibility of using the method.

Possibly the least problematic issue is the theoretical approach of the method. The intervention studies so far have demonstrated that even if the language in question has a nontransparent alphabetic orthography, the type of training that the GraphoGame method offers in providing learners with psycholinguistically relevant, consistent, and frequent segment sizes may well suffice to significantly support learners in their reading development. However, a possible foreseeable challenge could be in creating a systematic way of providing an appropriate game-like training environment for learning irregularities in the given orthography. This is especially important for orthographies that do not provide clear indications on smaller segment-level phonological features but, instead, on morphological and semantic features of the language. To overcome such challenges, the GraphoGame method probably needs to evolve somewhat so as to rely not only on the form, but also to take into account the meaning of the

segments. For instance, for languages with logographic orthographies (e.g., Mandarin Chinese), apart from the obvious challenge of the huge number of individual characters to be learned, the numerous homophones need to be presented in a manner that clearly provides sufficient clues to the meaning of the word. To accomplish this, larger contextual and semantic cues may need to be included in the training method.

Another theoretically and environmentally challenging issue concerns how to train learners with apparently disparate spoken language backgrounds. The basic principle of the GraphoGame method is to provide training on the strongest native language of the learner so that the learner has the necessary awareness of the different features (mainly phonological, but also semantic and morphological) of the language. Once the game version has been developed for the language of the learner, the language background is not a problem. However, there seems to be an increasing number of learners whose language background and living environment include several spoken languages. Moreover, a lack of appropriate reading material in the target language, as well as instances when the teachers do not know sufficiently the language that their pupils speak and are learning to read, further complicates the situation. These challenges, for both the learner and the teacher, can be overwhelming and might present an ideal situation to start testing the GraphoGame method as a training support, provided that the appropriate language version of the game has been developed.

One possible methodological challenge for using GraphoGame as a reading support is that learning skills and strategies can vary greatly between players. Obviously this challenge is most likely shared with many reading-support methods. Some struggling learners might require more explicit instructions, training content related to their specific problem areas, and/or advice and feedback than the game environment currently provides. Another potential challenge might come from the game being easy to use even without adult supervision. Thus, children can be left alone in their training for however long they want to play. Obviously, when children are not tired and have enough time to concentrate, they may prefer playing for extended sessions. However, this is not recommended. Our view is that playing sessions of 8–12 minutes seem to be the optimal for children's concentration during training. Longer playing sessions lead to an increased likelihood of the learner losing interest in the tasks—as may happen also if the children start using the game when they are too young or not intellectually mature enough. Our experience tells us that the optimal age for starting to use the game is close to 7 years.[8] At that age, children's brains are mature enough, even if some learners may be slightly delayed in maturation, which may be typical among struggling readers.

The overall training period must be extensive enough to see significant improvement in skills. Some children might need to have someone overseeing their progress and possibly providing motivational support. In fact, the game developers have received feedback from parents and teachers that some children seem to concentrate and perform better in the game with adult supervision and encouragement. However, the opposite feedback also has been received: Some players progress and concentrate well independently, and prefer this opportunity. Additionally, it is easy to understand that concentration cannot be optimal if other sounds (e.g., people talking) are audible when a child is training with GraphoGame. Effective learning via GraphoGame requires an undisturbed opportunity to concentrate fully on the sounds presented. Even adults who have tested the method in various settings have noted the need for a quiet environment and good quality headphones during GraphoGame use.

Another methodological challenge, yet probably an advantage of GraphoGame as well, is that it is available online; thus the progression of the player in the game can be synchronized so that the player can continue from where he/she last stopped, even if using a different connected device. Naturally, in order to take advantage of this feature, the device needs to be connected to the online network, at least at the beginning and end of each playing session. With only online access, when the connection is lost or unavailable, the game is inaccessible to players. The game can be downloaded to work offline, but with the disadvantages that playing time and progression cannot be easily monitored, feedback to learners is limited, and automatic updates of the game are not available.

Because GraphoGame is a digital game environment, technological challenges are evident. This technological learning environment has been developed so that it can be played on various platforms. Players can use the PC versions using Windows, Mac, or Linux operating systems. Recently, the game has been developed for Android operating systems used in computer tablets and smart phones. The constant changes in technology (i.e., new devices, changes in the displays, changes in the operating systems, etc.) make it challenging for the game developers to maintain the game to function with newly developed trends. One source of extra development work recently results from the fact that the game had been using the Java engine by Oracle. However, due to the unreliability and constant changes of the Java engine, GraphoGame developers are currently developing a new version that uses the Unity game engine by Unity Technologies. Thus, the new game will be more self-contained and users will not be required to download and/or update other software to run GraphoGame. The added benefit is that it eliminates the need for game developers to continually supply adjustments due merely to the changes to the game engine. The other advantage of using the Unity game engine is that it facilitates multiplatform publishing.

A different technological challenge might be how teachers and teacher education are tuned into using technology-enhanced methods in the classroom, and specifically for supporting struggling learners. Naturally, the fact that such technology-enhanced methods could be sensibly integrated into teaching practices depends on the condition and accessibility of suitable equipment in schools. In addition, cultural and age- and gender-specific issues may play a role here. Younger, digital-age teachers, who most likely have experience using technology outside their work environment, might have fewer mental obstacles toward employing technology as a part of their classroom work. By integrating technology into teacher education, however, the possible negative attitudes might diminish, thus enabling the effective use of technology in a supporting role in classroom work.

In describing the possible challenges for using the GraphoGame method, we note that not all challenges are necessarily insurmountable and may not affect all users. Perhaps the most challenging obstacles for the usability and feasibility of the GraphoGame method, therefore, are those that come from outside the method itself. The most fundamental obstacle might be in how learners gain access to the game. Although the number and spread of digital devices around the world is increasing rapidly, even developed Western societies still lack sufficient devices in schools. The lack of devices is even more consequential in the developing countries. However, the prices of sophisticated technological devices and online network fees seem to be decreasing continually, and the devices are becoming more durable. Thus, we may see in the near future that all school children will have access to sophisticated online devices and, hopefully as well, a wide diversity of technology-enhanced learning tools when they enter school.

In Finland, the Ministry of Education and Culture supports the delivery, maintenance, and user support for the Grapholearning technology (both technical and content) to address reading and math difficulties in young learners. The Finnish versions of GraphoGame (known as Ekapeli) are provided via the specialized LukiMat service,[9] which is run by the Niilo Mäki Institute. The LukiMat service offers a technological learning environment not only for those learning to read but also for those needing special support for developing their basic numeracy and math skills. The financial support from the Ministry makes it possible to provide this service within Finland at no charge. Currently the game seems to reach all the learners for whom it was originally designed, that is, the struggling learners at the end of kindergarten and in the two first years of school. In Finland, each age cohort has, on average, 60,000 children. Data from the player logs indicate that more than 20,000 children are playing the language training version regularly. Such numbers indicate that the target group—the struggling readers—has been reached. Moreover, GraphoGame offers versions for training fluency skills aimed at children who already have basic decoding skills, offering further practice in automatizing their skills. Altogether, the GraphoGame has supported nearly 200,000 young readers in Finland since it was launched.

When the support is extended beyond the Finnish context, we first seek to gain evidence on the effectiveness of the game in the various language environments and cultural settings. A prerequisite is that experts who are well informed about the language and its orthography, the local reading instruction practices, and the target culture in general are involved in developing the new language version of the game, in collaboration with the developers of the GraphoGame method. Additionally, local experts are needed to provide ongoing user support when the game is delivered and implemented, particularly after the game versions are extended beyond the research context. All this highly ambitious effort takes time and resources. Without a significant joint collaboration, successfully developing and spreading this scientifically grounded technological learning environment would be impossible. Intensive cooperation between researchers, practitioners, policy makers, and foundations is vital. Therefore, an international organization, the GraphoWorld Foundation, is being formed specifically for this purpose.

ENDNOTES

1. GraphoGame is the registered trademark of the University of Jyväskylä and Niilo Mäki Foundation for a noncommercial computerized game aimed at learning to read.
2. The phoneme is a concept that refers to the smallest speech unit, meaningless on its own but by using, omitting, or replacing it with another phoneme the meaning of the word can change. Phonemes are the abstract representatives of many different concrete sounds that share similar features. Thus, phonemes as such do not exist concretely—they are abstract concepts similar to graphemes in written language. One can say they may exist only because we have invented writing systems.
3. The grapheme refers to the smallest unit of written language that can change the meaning of the context in which it appears but that is not meaningful on its own.
4. Alphabetic languages are those with orthographies that use alphabetic symbols to convey or represent the pronunciation of the language.
5. The concept *rime* refers to a linguistic unit—that is, a spelling pattern of a word—that consists of the vowels and the subsequent syllable/word final consonants that maintains its sound in any context. *Rhymes* refer to pronunciation of the word with final vowel or vowel–consonant units that sound the same independently, no matter how they are spelled.

6. In presenting the linguistic elements of this paper, we use the following linguistic standards: Square brackets are used for indicating phonetic transcription (i.e., pronunciation), slashes are used for phonemic transcriptions, and letters, syllables, or words are italicized.
7. It should be noticed that this literacy policy was announced in 2013 and implemented in 2014. Previously, literacy instruction was provided in the local languages only in the first grade, with English-language instruction beginning in Grade 2. Now the local language is the medium for instruction from first through fourth grades, with English introduced as a subject in Grade 2.
8. The age at which children enter schooling varies by country. In some countries, children may be just 5 years old in first grade, and thus beginning their reading lessons before the optimal mental maturity age of 7. Therefore, the GraphoGame researchers and designers are currently developing different types of game activities appropriate for younger children (5 year olds).
9. More information on the LukiMat service is available at www.lukimat.fi

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