Using Cognitive Load Theory to Improve Text Comprehension for Students with Dyslexia

André Tricot[1], Geneviève Vandenbroucke[1] and John Sweller[2]

1. Cognition, Language and Ergonomics Lab and School of Education

French National Centre for Scientific Research and University of Toulouse, France

2. School of Education

University of New South Wales, Australia

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Corresponding Author Contact Details

André Tricot, CLLE Lab, University of Toulouse, 5 allées Antonio Machado, 31 058 Toulouse cedex, France. Andre.Tricot@univ-tlse2.fr

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Author Biographies

André Tricot is a Professor of Psychology at the School of Education, University of Toulouse. He was awarded his PhD in Cognitive Psychology (1995) from Aix-Marseille University, France. In 2014-15, he was the head of the group that designed grades 1, 2 and 3 of a new curricula for primary schools in France. André's main research topics concern the relationships between natural memory and processing (human cognitive system) and artificial memory (documents). Central to this research is the question of how designing artificial memory can help natural memory instead of overloading it. Applications are in instructional design, human-computer interaction, ergonomics, and transport safety.

Geneviève Vandenbroucke has taught French and Applied Linguistics at the School of Education, University of Toulouse, since 2004. She was a member of the team who created the master degree in Special Needs Education in 2012. In 2016, she was awarded a PhD in Applied Linguistics on the effect of text presentation in improving comprehension for grades 4 and 5 students with dyslexia.

John Sweller is an Emeritus Professor of Education at the University of New South Wales. His research is associated with cognitive load theory. The theory is a contributor to both research and debate on issues associated with human cognition, its links to evolution, and the instructional design consequences that follow. Based on many randomized, controlled studies carried out by investigators from around the globe, the theory has generated from our knowledge of human cognitive architecture, a large range of novel instructional designs.

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Abstract

Cognitive load theory (CLT) is a theory of instructional design built on our knowledge of human cognitive architecture. Based on the cognitive demands imposed by learning materials and instruction, the theory provides guidelines to manage learning tasks in order to increase knowledge. Whereas most students after grade 3 have automatized word recognition (with variations depending on several factors, such as the language domain), students with dyslexia do not fully automatize word recognition. Therefore, when they read texts, word recognition is so demanding that they have fewer cognitive resources available for comprehension. CLT can be applied to increase text comprehension for students with dyslexia, but, as far as we know, has not been used for this purpose. The chapter discusses how diverse, and sometimes contradictory, literature on increasing text comprehension for students with dyslexia can be interpreted and harmonized through CLT. Implications for practitioners are provided that summarize efficient ways to facilitate text comprehension for students with dyslexia — such as by changing text presentations, applying general CLT principles for students with limited cognitive resources, and using explicit instruction. We conclude that CLT has potential for facilitating learning to read by students with dyslexia.

Keywords: cognitive load theory; comprehension; reading; dyslexia; instructional design

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Introduction: Cognitive Load Theory and Dyslexia

Cognitive load theory is a theory of instructional design based on our knowledge of human cognitive architecture (Sweller, Ayres & Kalyuga, 2011). It provides guidelines to manage learning tasks and the cognitive demands imposed by learning materials in order to increase knowledge. These guidelines have been verified empirically and replicated. The theory distinguishes between cognitive demands required to process and acquire information intrinsic to the material and task, known as intrinsic load, by for example, elaborating knowledge — and processing useless information imposed by instructional procedures, known as extraneous load (Sweller, 2010).

During text reading, we can distinguish between reading itself (*i.e.* recognising words) and comprehension (*i.e.* elaborating a situation model; see for example Gough & Tunmer, 1986). When grade 1 students (approximately 5-6 years of age) start to learn to read, they face this double cognitive demand: They expend cognitive resources on recognising words and, at the same time, they try to understand the text. This demanding double task is very challenging for many novices, but after months and years, students in grades 2 and 3 (approximately 7-9 years of age) progressively automatize word recognition, depending on the regularity of the correspondence between the spoken and written language they are learning (for example, students learn to read Italian or Spanish faster than English; correspondences between sounds and letters are more regular in Spanish and Italian than in English; Ziegler & Goswami, 2005). The more that recognising words is automatized, the more resources are available for comprehension.

According to the Diagnostic and Statistical Manual of Mental Disorders (DSM-5, American Psychiatric Association, 2013), dyslexia is a specific learning disorder, involving reading. Many students with dyslexia have a specific difficulty in automatizing word recognition, probably based on phonological skill deficiencies associated with phonological coding deficits (Vellutino, Fletcher, Snowling, & Scanlon, 2004). Therefore, while most students after grade 3 have automatized reading and are able to understand texts, students with dyslexia have difficulty understanding texts, not because of the comprehension process itself, but because they lack resources to deal with it. Nevertheless, recommendations on how to present text for readers with dyslexia (*e.g.,* see the British Dyslexia Association, 2014) are "not based on empirical evidence and does not include recent findings" (Schiavo & Buson, 2014, p. 2). Furthermore, those recommendations are not specific to readers with dyslexia (Evett & Brown, 2005). CLT may therefore be a relevant framework to consider how we should manage cognitive resources for students with dyslexia who are learning to comprehend written text, assuming text comprehension involves the double task of recognising words and understanding text.

In this chapter, we first will present cognitive load theory (CLT from here), then in the second part we will discuss dyslexia and the way it decreases comprehension. In the third section, we will present and discuss previous results of research designed to improve reading and comprehension for students with dyslexia. Taken together, we will outline CLT from a specific perspective: Decreasing extraneous mental effort to free resources to assess reading comprehension for students with dyslexia. Following this, implications for practitioners and future research directions are discussed.

Theory

Cognitive Load Theory, Instructional Design, and Educational Psychology

Cognitive load theory (Sweller, 2015, 2016; Sweller, Ayres, & Kalyuga, 2011) is an educational psychology theory concerned with instructional design. The aim of this theory is to generate knowledge that teachers can use when they design learning tasks and materials in order to improve students' learning. The theory can be considered under four headings: categories of knowledge; human cognitive architecture; categories of cognitive load; and, instructional design.

Categories of knowledge

Knowledge can be categorised by its biological, evolutionary status (Geary, 2008, 2012; Geary & Berch, 2016). Biologically primary knowledge is knowledge we have evolved to acquire over many generations. Examples are learning to listen to and speak a native language, learning basic social activities, learning to recognise faces, and most generic-cognitive skills such as general problem-solving skills or self-regulation skills (Tricot & Sweller, 2014). Biologically primary knowledge is characterised by the relative ease and speed with which it is acquired, the fact that it does not need to be explicitly taught, and that it can be acquired unconsciously.

In contrast, biologically secondary skills are skills that we need for cultural reasons and that we have not specifically evolved to acquire. They tend to be acquired relatively slowly and with conscious effort. Acquisition is facilitated by explicit instruction. Educational institutions were developed in order to teach biologically secondary knowledge such as reading and writing because otherwise most people will not acquire those skills. Most such skills are domain-specific in nature rather than generic-cognitive (Tricot & Sweller, 2014). As an instructional theory, CLT deals principally with the acquisition of biologically secondary knowledge such as learning to read.

According to his theory (Geary, 2008), several learning disorders are associated with primary knowledge (*e.g.*, autism), whereas other learning disorders are associated with secondary knowledge (*e.g.*, dyslexia, dyscalculia). Biologically primary, neurodevelopmental disorders are considered as "general", with several aspects of development impaired. Biologically secondary, neurodevelopmental disorders are "specific" with only one aspect of development impaired for a specific learning disorder. Biologically primary disorders are independent from cultural contexts, whereas biologically secondary disorders are highly dependent on a cultural context.

Human cognitive architecture

The manner in which biologically secondary knowledge is acquired mimics the manner in which evolution by natural selection allows the accumulation of genetic information. The process can be described by five basic principles each of which provides an example of biologically primary information. We do not need to be taught how to drive the mechanisms that each principle describes.

- *The information store principle.* Human cognitive architecture relies on the acquisition of a huge store of information. Long-term memory provides that store.
- *The borrowing and reorganising principle.* Because of the size of the information store, we require a procedure to rapidly acquire large amounts of information. We do so by borrowing information from others by listening to them, reading their texts, and imitating them. Borrowed information is altered by current information held in long-term memory.
- *The randomness as generation principle.* When required information is unavailable from others, we can generate it ourselves during problem solving using generate and test procedures. While much less efficient than borrowing information from others,

random generate and test is the only available process when information from others is unavailable.

- *The narrow limits of change principle.* In order to protect the contents of long-term memory from random and deleterious alteration, a procedure is needed to ensure that changes to the memory store are slow and tested for effectiveness. Working memory has the necessary characteristics. When processing novel information for eventual storage in long-term memory, working memory is severely limited in capacity and duration. Those limitations prevent rapid, large alterations to long-term memory that could limit or even destroy its functionality. Until recently, working memory was assumed to remain constant for any given individual. Chen, Castro-Alonso, Paas, and Sweller (2018) suggested that working memory resources depleted with cognitive acivity and recovered with rest.
- *The environmental organising and linking principle.* Environmental cues are used to allow working memory to retrieve information from long-term memory that can generate action appropriate to the environment. There are no known limits to the amount of information that working memory can retrieve from long-term memory. It is through this principle that education has its transformative effects. It allows us to engage in activities that we could not possibly otherwise contemplate.

This cognitive architecture provides a base for CLT. The aim of education is to store appropriate information in long-term memory. That information, via the environmental organising and linking principle, then allows us to function effectively in a range of environments in which we otherwise would be unable to function. Of course, the information first must be acquired via a working memory that is severely limited when acquiring novel information. If working memory is overloaded, as frequently happens, it can cease to function. As indicated in the subsequent sections, while these processes apply to the general population, they are at least equally important and may be even more important to dyslexic learners.

Categories of cognitive load

There are two basic, independent categories of cognitive load, intrinsic and extraneous, as well as germane load, which is a third, derivative category (Sweller, 2010).

- *Intrinsic cognitive load.* This load refers to the basic properties of the task that only can be altered by either changing the task or changing the expertise of the learners. Intrinsic cognitive load depends on element interactivity. If elements of information that must be processed interact, they must be processed simultaneously in working memory, resulting in a working memory load. For example, when learning to read the word “cat” there are three elements (C, A and T) that must be processed simultaneously by someone who has learned the alphabet. For someone who has not learned the alphabet, there are many more than three elements that must be processed. For a person who is a skilled reader, “cat” may be processed as a single element: the written word “cat”, that corresponds to the spoken word /kæt/ and to the meaning of this word. Thus, element interactivity is a combination of the nature of the information and the expertise of the learner. Students with dyslexia do not easily automatize the recognition of the written words; therefore, while the intrinsic cognitive load when reading reduces rapidly for the general population, it may remain very high for dyslexic readers.
- *Extraneous cognitive load.* The manner in which information is presented and the activities required of learners also affects element interactivity and thus cognitive load. In this case, cognitive load can be varied by instructional procedures and so is extraneous to the intrinsic properties of the task. For example, if students are required

to learn by problem solving, there are many more interacting elements that must be processed than if they learn by studying worked examples. CLT has generated a large range of instructional procedures that can be used to reduce extraneous cognitive load by reducing the element interactivity of the instructional materials. If reading (*i.e.* decoding words) is the immediate learning goal, but instruction emphasises comprehension (*i.e.* building the meaning of text), then that instruction will impose an extraneous cognitive load for students with dyslexia who cannot build the meaning of text if they cannot decode the text.

- *Germane cognitive load.* While intrinsic and extraneous cognitive load are the only independent sources of cognitive load, the term *germane cognitive load* is sometimes used to refer to the working memory resources that are needed to deal with intrinsic load rather than extraneous load. If, in line with the above example, dyslexic students who have not learned to decode text are instead provided with instruction intended to assist them in deriving meaning from text (an impossible task if they cannot decode), then germane load will be low. Such instruction oriented towards deriving meaning will require students to devote working memory resources to issues irrelevant to decoding text. Germane cognitive load will be low because resources are not devoted to the intrinsic load associated with decoding text. If instead, working memory resources are devoted to the intrinsic load which is germane to decoding text rather than deriving meaning, germane load will be high.

Instructional design

Using CLT, since the mid-1980s (*e.g.,* Owen & Sweller, 1985; Sweller & Cooper, 1985), many randomized, controlled experiments have been published, most of them comparing an experimental group and a control group, with both groups subjected to the same pre-test (if used) and post-test. These experiments investigated CLT effects to reduce extraneous, or even intrinsic load, in order to free as many cognitive resources as possible for learning. As far as we know, CLT has been used very rarely in the domain of special needs education and so the possible relevance of this theory to this domain has not been extensively explored. Lee and So (2015) provide one example. Using CLT to analyse the difficulties of intellectually disabled students during inquiry learning, they showed that intellectually disabled students need to be carefully guided to participate in inquiry and to manage the cognitive loads. But what the authors showed was also valid for any students (Lazonder & Harmsen, 2016). There is every reason to suppose that the theory could be used when designing materials for students with specific learning disabilities, like dyslexia. Accordingly, when discussing dyslexia, we will present reading (decoding words) as a means, and comprehension as a goal, in order to show that CLT is applicable to the problem of students who face specific difficulties in reading.

Reading and Comprehension

Reading is a complex activity. According to the Simple View of Reading model (Gough & Tunmer, 1986), reading comprehension is the product of two skills: Decoding and oral comprehension. Decoding is defined as “the ability to rapidly derive a representation from printed input that allows access to the appropriate entry in the mental lexicon, and thus, the retrieval of semantic information at the word level” (Hoover & Gough, 1990, p.130). It is biologically secondary in that we have not specifically evolved to read (Geary, 2008). For that reason, learning to decode must be taught explicitly in educational contexts.

Oral comprehension is defined as “the ability to take lexical information [*i.e.*, semantic information at the word level] and derive sentence and discourse interpretations” (Hoover & Gough, 1990, p.131). It is biologically primary because we have evolved to learn to listen and speak and so oral comprehension can be acquired without schooling, unlike decoding. While oral comprehension can be improved by schooling, all “typical” learners will learn oral comprehension. Accordingly, the cognitive architecture and cognitive load categories discussed above are more applicable to decoding than to oral comprehension.

High level cognitive processes are implied in comprehension (Van den Broek et al., 2005). Comprehension implies the construction of a coherent mental representation of what the text is about that the reader must memorize (Van Den Broek & Kremer, 2000). Situation is the basis of this mental representation (Van Dijk & Kintsch, 1983). To represent to themselves what the text says, the readers relate the discourse to some existing knowledge structure and relations between different aspects of information of the text so that they rebuild a new model of situation. There are many meaningful relations in a text and two types are particularly important: causal and referential relations. In addition, readers need to make inferences that are not directly present in the text (McNamara & Magliano, 2009). Such high level cognitive processes involve important attentional or working memory resources. Written comprehension depends on word identification too. The faster the letters and words can be processed during reading, the greater are the cognitive resources available for higher-level comprehension processes, as inferences and logical relations (Florit & Cain, 2011; Snowling, 2013; Vellutino, Tunmer, Jaccard, & Chen, 2007).

So, it is very important for young readers to automatize word identification. This automatization is based on knowledge of the alphabetic principle - the relationships between the letters (graphemes) of written language and the individual sounds (phonemes) of spoken language. According to the dual-route cascade model for reading (Coltheart, 1978), two different routes exist by which word recognition can occur. The first is a direct lexical route. The reader accesses the representation of the word in memory. She or he does not need phonological abilities. This route allows the identification of real, including irregular words, that are known and present in the mental lexicon. The second is an indirect, non-lexical (assembled) route. Word identification is achieved by processing the graphemes, accessing their pronunciation, then putting these sounds together. To read, the reader needs to use the grapheme-phoneme correspondence rules. With this route, the reader can decode unknown words and pseudo-words.

Good phonemic awareness (Oakhill, Cain, & Bryant, 2003; Vellutino et al., 2007) and phonological awareness (Bianco et al., 2012) are important early indicators of later reading ability. When word reading becomes fast and automatic, a greater proportion of these processing resources can be devoted to reading comprehension. In other words, comprehension difficulties are not specific, they are the result of different and interacting factors such as: domain specific knowledge about the text topic, vocabulary knowledge, inadequate print exposure, comprehension monitoring difficulties, motivation, depth of processing, etc. (Cornoldi & Oakhill, 2013). One of these factors is reading skill, *i.e.* recognizing or decoding words.

Dyslexia as a Specific Learning Disorder

Dyslexia is a specific learning disorder, *i.e.* “a developmental disorder that begins by school-age, although it may not be recognized until later” (DSM-5, American Psychiatric Association, 2013), involving reading. The prevalence of dyslexia depends “upon the precise definition and criteria that are used for its ‘diagnosis’ with estimates ranging from 3% to 10%” (Snowling, 2013, p. 8) and “it is generally agreed that more boys than girls are affected” (p. 7). It also depends on the language itself (e.g., if the written form is alphabetic or not), and how regular is the correspondence between letters and sounds (Ziegler & Goswami, 2005). According to the DSM-5 (American Psychiatric Association, 2013), dyslexia is persistent across the lifespan and readers with dyslexia have decoding performances below the mean (<1.5 standard deviation, which corresponds to a difference of at least 18 months between reading age and cognitive age). Exclusion criteria are normally used to define specific learning disorders such as dyslexia, for example: (low) IQ, emotional, vision, hearing, or motor skills problems are excluded from dyslexia (see also the International Classification of Diseases – ICD-10; World Health Organization, 2016).

The DSM-5 (American Psychiatric Association, 2013) specifies three areas with a deficit for specific reading disorder: (1) accuracy of reading words; (2) fluency in recognizing words and reading fluency (the ability to read a text by controlling prosody and punctuation, by incorporating pauses, and by segmenting the text in syntactic units); and (3) written text comprehension.

The relationships between reading comprehension difficulties and dyslexia are not simple. According to Snowling (2013, p. 9), “some children with dyslexia have problems with reading comprehension, which are attributable to slow and inaccurate word reading, leaving few attentional resources available for comprehension. However, reading comprehension impairment can occur in the absence of poor decoding, suggesting that it is a distinct disorder. Indeed, the profile of reading comprehension impairment contrasts markedly with dyslexia”. This quote is useful to understand that in this chapter we will present different ways that have been explored in the literature on improving comprehension for students with dyslexia. Several techniques to improve reading are general and focused on comprehension. Although they are generally efficient, most are non-specific to students with dyslexia; however, as discussed below, others are specific to dyslexia and focused on reading. Therefore, dyslexia can be considered as a specific learning disorder that increases cognitive load during reading. For example, as indicated by Snowling in the above quote, if word reading requires considerable cognitive resources, fewer resources will be available for comprehension.

Causes of Dyslexia

According to Ramus and Ahissar (2012), there are many explanations for the aetiology of dyslexia—and which have implications for the application of CLT in assisting students with dyslexia. Although there is a dearth of knowledge of cognitive processes and diverse profiles due to the nature of testing tasks used in identifying the deficit, there is a consensus with respect to several points:

- Dyslexia is highly heritable (Snowling, Gallagher & Frith, 2003; Snowling & Hulme, 2013). Studying monozygotic and dizygotic twins yields interesting results. If one twin is dyslexic, about 68% of the time, the second twin also will be dyslexic for monozygotic twins who are genetically identical. For dizygotic twins, the percentage is 38% (Fisher & DeFries, 2002).
- The most common psychological cause of dyslexia is a deficit in auditory processing of the sounds of the language (phonological processing). This phonological hypothesis is generally recognized as robust. During the last thirty years, the phonological explanation has been supported by many research studies in many different alphabetic written languages such as Finnish, Italian, English, French, or Greek (Landerl et al., 2013), but also non alphabetic languages like Arabic (Elbeheri & Everatt, 2007) or Chinese (Ho, Law, & Ng, 2000). The main deficits correspond to difficulties with phonological coding and representation, phonological short-term memory, and mobilization of language sounds. Landerl et al. (2013) showed that phonological awareness (best indicators are rapid naming tasks and deletion phonemes tasks) for 8 to 11 year old students with dyslexia (compared to a control group) is the best predictor of dyslexia. Nevertheless, these indicators are more significant for non-transparent languages (*i.e.* where reading a letter is not enough to guess what the corresponding sound is, because correspondence between sounds and letters is irregular) like English and French. In addition, these deficits occur early (Carroll & Snowling, 2004).

- An auditory, phonological processing deficit clearly can be classed as biologically primary. In other words, while reading is highly domain-specific, classed as and requiring biologically secondary knowledge, it is based on general, biologically primary knowledge: the ability to hear and to segment spoken language (Landerl et al., 2013). When this primary ability is impaired, its consequence is a specific learning disorder called dyslexia. It is difficult to understand how the impairment of this primary ability is observable only during reading, not during understanding or producing oral language. A new hypothesis is needed to explain this phenomenon.

Towards a New Hypothesis

A new hypothesis concerning phonological deficit has been put forward in the last few years. According to this hypothesis, people with a specific reading disorder do not have their phonological abilities degraded, but rather, it is their access to phonological representations that are affected. Ramus and Szenkovits (2008) conducted a series of experiments which led them to conclude that “the phonological representations of people with dyslexia may be intact, and that the phonological deficit surfaces only as a function of certain task requirements, notably short-term memory, conscious awareness, and time constraints” (p. 219). Persons with dyslexia fail to discriminate and repeat correctly verbal material, as soon as short-term memory load is significant, for example, in a letters span task when the length increases. But their performance is not different from “typical” readers in low memory load conditions. For example, when they have to recall phonologically different ([gum] and [taz]) and similar ([taz] and [taʒ]) words or non-words, their performances are poorer when similarity is high, like typical readers). According to Ramus and Szenkovits (2008), this reflects the fact that, in the course of language acquisition, dyslexic children develop normal phonological representations.

Brain-based research into phonological representation by Gabrieli (2009) showed that dyslexics have alterations of white matter, whose role is to ensure the conduction of nerve impulses between two consecutive nerve centres, or between a nerve centre and a nerve. A study by Boets et al. (2013) conducted on 23 dyslexic adults and 22 “typical” readers confirmed this hypothesis. Participants were subjected to a series of functional magnetic resonance imaging tests. The results indicated slow access to phonological representations. The arched beam that transmits signals between the upper left temporal gyrus (where Wernicke's area is located) and the lower left frontal gyrus (where Broca's area is located) showed an alteration from normal white matter. Boets et al. (2013) and Ramus (2014) shared the same hypothesis.

Research on dyslexia also indicates a problem in working memory among dyslexic students. On the one hand, the processes involved in working memory are used for decoding at the expense of working memory resources for processing inferences (Cain, Oakhill & Bryant, 2004). On the other hand, there is a shortfall in the supply of working memory resources, whether for storage or processing capacity (Fischbach, Könen, Rietz, & Hasselhorn, 2014; Malstädt, Hasselhorn, & Lehmann, 2012). This could explain comprehension deficits. The treatment of complex sentences (with passive tense, for example) would be more difficult for 10-11 years old students with dyslexia, because of phonological and working memory deficits (Leikin & Bouskila, 2004). But it still remains very difficult to understand how this working memory deficit could be a cause and not just a consequence of a word recognition deficit (Cain, Oakhill, & Bryant, 2004).

It therefore appears that reading comprehension in dyslexic students may be deficient due to a lack of word identification automation. In turn, this deficit causes a working memory deficit. How can we improve this identification so that the comprehension goal can be fully achieved? We now will examine CLT perspectives on this issue. We will first examine how

CLT can be used to increase learning for students with reduced cognitive resources, a relevant factor, but not specific to students with dyslexia. After that, we will examine CLT effects specifically designed to decrease load involved in recognizing words, *i.e.* specifically relevant for students with dyslexia.

CLT Effects can Increase Learning for Students with Reduced Cognitive Resources

In CLT, the expertise reversal effect is an effect that depends heavily on the environmental organising and linking principle. Based on this principle, the accumulation of relevant knowledge in long-term memory increases the cognitive resources available to learners. There are no known limits to the amount of information sourced from long-term memory that can be processed in working memory. If students have reduced cognitive resources, the most straightforward way of rectifying that problem is to increase their expertise. Once expertise has been increased, the effectiveness of various instructional designs alters. According to the expertise reversal effect, instructional designs that are beneficial for novice learners might be detrimental for more expert learners. This effect was identified almost 20 years ago (Kalyuga, Chandler, & Sweller, 1998), with the first synthesis and extensive theorizing published 5 years later (Kalyuga, Ayres, Chandler, & Sweller, 2003), followed by a special issue of the journal *Instructional Science* (Kalyuga & Renkl, 2010). The expertise reversal effect partly corresponds to an effect previously known as aptitude treatment-interactions (Cronbach & Snow, 1977; Tobias, 1976).

Expertise reversal is a compound effect that can be applied to any primary effect obtained in CLT. This makes it possible to predict, for example, that the most advanced students will learn more efficiently when solving problems, while the least advanced students will be more effective with the same problem presented with its solution, *i.e.* a worked example (Kalyuga, Chandler, Tuovinen, & Sweller, 2001). Thus, within the same classroom, different students can achieve the same learning, with the same problems, but presented differently. In this way, it is possible to differentiate task and materials and, at the same time, maintaining the same learning goal for all.

This approach is very promising because it considers students' prior knowledge as a major source of the difference between individuals. As indicated above, this knowledge is considered domain-specific (Tricot & Sweller, 2014). Thus, the level of difficulty each student faces depends on the distance between the student's prior knowledge and the knowledge that needs to be acquired, plus the characteristics of the task. Difficulty is therefore understood as a characteristic of the situation, not the student. Under this approach, therefore, there is no reason to consider that a student may have a learning disability in general. This corresponds exactly to the definition of specific learning disorders.

CLT has been used to formulate a set of concrete procedures for adapting a task or the presentation of materials according to students' levels of relevant domain-specific knowledge (see Sweller, Ayres, & Kalyuga, 2011). Next, we will explore CLT-procedures that are specifically relevant for students with dyslexia.

Specific CLT Effects that can Increase Comprehension for Students with Dyslexia

If reading is very demanding for students with dyslexia and reading is not the learning goal itself, then, based on CLT, we should try to decrease the extraneous load associated with reading in order to free germane resources for the intrinsic load devoted to comprehension. Four CLT effects seem relevant for this purpose.

The modality effect. This occurs when spoken text is better than written text. This effect could support the hypothesis that listening to text instead of reading should improve comprehension by reducing cognitive load involved in reading. (Note that listening is only superior to reading for low element interactivity material due to the transient information effect, discussed below). This hypothesis is supported by research in the domain of improving text comprehension for students with dyslexia. Several experiments tested if oral presentation of textual material (vs. written presentation) increased comprehension for students with dyslexia (see Wood, Moxley, Tighe, & Wagner, 2018, for a review). These experiments showed that oral presentation decreases reading demand, therefore increasing comprehension.

In a slightly different way, Kendeou, van den Broek, Helder, and Karlsson (2014) argued that with struggling readers, non-written media can be used to foster skills that are important to reading comprehension. According to them (p. 13), “the use of different media preserves their working memory resources (which would otherwise be expended on decoding) and allows them to engage in higher level processes”. But these researchers were more focused on teaching comprehension (making inferences) than on directly increasing comprehension. According to CLT, making inferences and comprehension is based on biologically primary knowledge. They cannot be taught to ”typical” students because they are learned automatically. For students missing this biologically primary skill, it may be possible to compensate, with considerable effort, via the biologically secondary system. Students with limited working memory resources during reading may be taught to focus their attention on comprehension and making inferences. As for any complex activity that involves several sub-goals, it is possible to remind students that they have to reach this or that sub-goal.

Ginns (2005) published a meta-analysis on the modality effect. This extensive review showed that, even if the modality effect is robust, it applies to multimedia materials, where the goal is to understand complex and interactive text-picture presentations. In these cases, presenting the comments orally instead of in written form decreases cognitive load and increases learning. According to Ginns (p. 320), the modality effect’s main hypothesis is: “presenting instructional materials using a combination of an auditory mode for textual information, such as spoken text, and a visual mode for graphical information, such as illustrations, charts, animations, etc., will be more effective than presenting all information in a visual format, such as printed text with illustrations, charts or animations." The modality effect may be particularly relevant to dyslexic students with listening skills that are more adequate than their reading skills.

The transient information effect. This is a second cognitive load effect that may be relevant. It occurs when permanent instructions such as in written form are transformed into equivalent transient information such as in spoken form, resulting in a decrease in learning (Leahy & Sweller, 2011). This effect suggests that listening to high element interactivity text instead of reading may not improve comprehension because of the transience of spoken language. Note that the transient information effect is obtained with long, complex texts (Wong, Leahy, Marcus, & Sweller, 2012). With short texts, the classic modality effect is obtained and the negative effect of transience disappears.

This hypothesis is supported by several negative results obtained in the domain of improving text comprehension for students with dyslexia when providing them oral presentations instead of textual material. These experiments failed to demonstrate increased comprehension when dyslexic students were presented text in oral rather than written form. We will present one of these studies later in this chapter. With this solution, there is no redundancy between two different presentations of the same text, but only one presentation, the oral one. This presentation is transient: once a student hears a word, the presentation of this word disappears, even if the student does not understand the word. Therefore, if on the one hand, it appears that using an oral presentation might be a good way to reduce cognitive load for students with dyslexia by decreasing the load involved in reading, on the other hand, the transient information effect predicts that oral presentations will increase cognitive load, because they rely on transient information.

The redundancy effect. This effect may also be relevant to dyslexia. Reading and hearing the same text at the same time is redundant and decreases performance (Kalyuga, Chandler, & Sweller, 2004), but this result has been obtained with “typical” readers. With novices or students with specific reading disorders, the redundancy effect may disappear due to the expertise reversal effect. Hearing text may be important rather than being redundant for learners who have difficulty reading.

Indeed, this is the main result of Wood et al.’s (2018) meta-analysis on read-aloud text presentation. Presenting spoken and written text at the same time increases comprehension for students with dyslexia. But in this literature several aspects are unclear. First, the average positive effect is not strong with several experiments in the domain not obtaining a positive effect with a redundant presentation (*e.g.*, Hodapp, Judas, Rachow, Munn, & Dimmitt, 2007). Second, it is usually impossible to know if the participants were reading and hearing the text at the same time, or just reading, or just hearing—online data are not available. Third, several results showed that older students with dyslexia gained more from the redundant presentation than younger ones. For example, Lundberg and Olofsson (1993) designed a computer-based system that allowed the reader to request immediate pronunciation of a problem word encountered. According to the authors, one reason for this differential effect might be related to the metacognitive demands implied by the request option. However, the interactive feature of the support system also seems to promote metacognitive development.

The working memory resource depletion effect. This occurs when cognitive effort on one task depresses performance on a later task, with the two tasks having similar cognitive components. The depressed performance on the second task is due to a depleted working memory following cognitive effort on the first task. Those depleted resources can be restored during rest periods (*e.g.*, Tyler & Burns, 2008). CLT used this effect to explain the spacing effect (Chen et al., 2018), *i.e.* when information processing that is spaced over longer periods (spaced presentation) results in superior test performance compared to the same information processed over shorter periods (massed presentation).

The working memory resource depletion effect could be very important in improving text comprehension for students with dyslexia. Indeed, as we noted earlier, when reading a text in order to understand it, a reader needs to process two activities simultaneously: word decoding and comprehension. This dual-task is very demanding and that is why automatizing word recognition is so important, as it can free resources for comprehension. We can hypothesise that rest periods during reading should have a similar effect. During a pause, the reader has no words to recognize, freeing resources for comprehension. In the same way, rest periods during listening to a text should also increase comprehension. This hypothesised mechanism is analogous to the spacing effect (Chen et al., 2018)

As an example, it has been shown that when trying to understand a spoken document in a foreign language, adding a facility to pause and rewind during listening increases comprehension for most students (Roussel, 2011). (Note, that with lower level students in the relevant foreign language, a pause facility tends not to be used by the participants and accordingly, their performance is not increased.) A similar result was obtained by Schüler, Scheiter, and Gerjets (2013) in a written condition. When their participants were allowed to "replay" the linguistics materials, they re-read the single text segments more often. Replaying segments was positively correlated with learning outcomes. When learners can process the same material several times it can improve learning (see meta-analysis by Therrien, 2004).

It is also worth noting that this expectation is supported by the Time Based Resource Sharing model of working memory (Barrouillet & Camos, 2015). When processing a dual-task, the performance on one sub-task is related not just to the number of information units to be processed to perform the other sub-task, but also to time spent on processing the other sub-task. If an individual has more time to process the same second task, then cognitive demand is decreased and performance increased on the primary task.

Hypotheses Generated by CLT: What Should and What Should Not Work

The four CLT effects we examined above can generate the following hypotheses with respect to increasing comprehension for students with dyslexia by decreasing load devoted to word recognition:

a. Adding spoken presentation of texts to written presentation of texts increases comprehension only when the texts are short and simple;
b. Using spoken presentation of texts instead of written presentation of texts decreases comprehension, especially when the texts are long and complex;
c. More time to read, for example by adding pauses during reading, increases text comprehension;
d. Younger students with dyslexia find text comprehension difficult under any condition.

Research: Previous Results in Improving Reading and Comprehension for Students with Dyslexia

Different strategies have been tested to improve reading and comprehension for students with dyslexia. In the sections to follow, we outline three sets of strategies that sought to enhance comprehension among students with dyslexia. One set of strategies addressed reading itself. Specific training materials were designed to train students with dyslexia in decoding words. Another set of strategies addressed the cognitive and metacognitive processes involved in comprehension. Students with dyslexia were trained to understand texts. The first two strategies were usually effective, but they were not specific to dyslexia and tend to be very inefficient. They did not directly use CLT. They were based on the same general principles for teaching reading and comprehension for "typical" readers. The third set of strategies attempted to decrease the cognitive demands of reading to increase comprehension, typically by presenting reading material orally in addition to or instead of presenting written texts. This third set of strategies was specific to students with dyslexia and they directly concerned CLT. They were thus far less demanding than the first two sets of strategies, but they were not very efficient. We will now present these three strategies and use CLT to discuss the results obtained using the third set of strategies.

Improving reading by training

The first set of studies sought to improve reading through training. In the context of rehabilitation, the effects of morphological training in several languages have been positive. For example, Colé, Casalis, and Dufayard (2012) developed training software, “Morphorem”, for dyslexic students in fifth-grade classes. With this tool, students improved their performance in several areas: morphological analysis, comprehension of suffixed words, and decoding. This approach is interesting when we consider that the morphological abilities of dyslexic students would be less degraded than their phonological skills (Casalis, Colé & Sopo, 2004) and that morphological knowledge determines the effectiveness of reading (Kirby et al., 2012).

Decoding skills training has also shown positive results with poor readers for decoding and phonemic awareness (McCandliss, Beck, Sandak, & Perfetti, 2003; Torgesen et al., 2001). A meta-analysis confirmed those results. Phonemic awareness instruction had a positive impact on reading for young children (preschoolers, kindergarten students, and first graders), even for disabled readers (Ehri et al., 2001).

An alternative proposal was based upon the idea that readers with dyslexia have difficulty processing sounds rapidly (Tallal, Merzenich, Miller, & Jenkins, 1998). “Fast ForWord” is a reading and language intervention program for struggling readers but it seemed that improvements, especially in phonemic awareness and reading, were not maintained over time (Hook, Macaruso, & Jones, 2001).

Ecalle, Kleinsz, and Magnan (2013) developed a syllabus-based, computer-assisted learning system. French grade 1 and 2 poor readers improved silent word recognition, word reading aloud, and reading comprehension after graphosyllabic training. Another experiment which used similar training confirmed the results, with poor readers improving reading fluency (Potocki, Magnan, & Ecalle, 2015).

Improving comprehension by addressing cognitive and metacognitive processes involved in comprehension

A second set of studies focused on improving cognitive and meta-cognitive processes. Literature reviews and meta-analysis of the research in this domain show that it is possible to use strategies that improve comprehension for every reader; that is, “typical” readers (Ehri et al., 2001) as well as readers with (general) learning difficulties (Gersten, Fuchs, Williams, & Baker, 2001; Joseph, Alber-Morgan, Cullen & Rouse, 2016; Mastropieri & Scruggs, 1997; Scammacca et al., 2007; Therrien, 2004). These studies showed that it is efficient to teach vocabulary, text grammar (*i.e.* the structure of a text genre), strategies to process anaphors and to make inferences, but also metacognitive strategies like answering questions about the text, self-questioning and self-explaining the text, monitoring and self-evaluating text comprehension, re-reading, etc. Group discussions of the text and reciprocal teaching also improved text comprehension (Murphy, Wilkinson, Soter, Hennessey, & Alexander, 2009). Most of these studies agree with the evidence that multiple strategies were more efficient than single strategy approaches, especially when general comprehension was evaluated.

There was one other important result from these reviews and meta-analyses: “Across all studies, those with only participants with learning disabilities had significantly higher effects than those with no participants with learning disabilities” (Scammacca et al., 2007, p. 17). This conclusion was interesting: if dyslexia is caused by gaps in biologically primary skills that do not need to be taught to learners in the “typical” range, we might expect that the biologically secondary system is required to plug those gaps, so explaining why the effects are larger when treating dyslexic learners.

Thus, improving comprehension for students with dyslexia is like improving text comprehension for every student, but specifically efficient for the dyslexic students. However, these strategies are general, demanding, and time consuming. CLT is useful because it can lead us to design interventions that are less demanding and more specific for students with dyslexia.

Improving comprehension by decreasing reading demands

The third set of studies sought to improve reading by reducing reading demands. A key way to improve reading for dyslexic students is to change the format in which information is presented. Thus, Zorzi et al. (2012) manipulated the written material and obtained an important result: increasing the spacing of letters of a word and words in a text improved the speed and quality of reading in Italian or French dyslexic children, without any previous training. They read an average of 20% faster and made half as many mistakes.

Schneps and his colleagues (2013) replicated the positive effect of spacing letters on comprehension for readers with dyslexia. But they also investigated line length, asking participants to read a text on a small device. The results showed that reading speeds increased by 27%, reducing the number of eye fixations by 11%, and importantly, reducing the number of regressive saccades by more than a factor of 2. But there was no effect on comprehension.

ALECTOR (Gala, 2016) is a project that aims to generate tools to help with the automatic transformation of texts in order to make content more accessible for children with dyslexia and weak readers. Gala and Ziegler (2016) conducted an experiment with simplified versions of texts with lexical, syntactic, and discursive (like anaphor deletion) levels. The results indicated a high reading speed and fewer reading errors (mainly lexical ones) with simplified versions.

Wood et al. (2018) published a meta-analysis on the effects of oral presentation of textual material on reading comprehension for students with dyslexia. The basic assumption of these approaches is that oral presentation of written material decreases the demands of reading, thus enabling comprehension (Olson, 2000). Previous literature reviews concluded that results in this domain were inconsistent. Wood et al.'s analysis concerned 22 studies. These studies included experiments where the output was not just comprehension but more general knowledge of particular subject matter (*e.g.*, reading, writing, math, science, etc.). The meta-analysis showed that the use of text-to-speech tools had a significant impact on reading comprehension scores with $d = .35$. Wood et al.'s analysis showed, like previous reviews, that the results in the domain were inconsistent, partially explaining the small effect size. For the moderator analyses, only a single, significant moderator emerged, namely, whether the study design was a between-subjects or within-subject study. The average weighted effect size for between-subjects studies alone was $d = .61$. For within-subject studies, the average weighted effect size dropped to $d = .15$.

In their meta-analysis Wood et al. (2018) did not discuss two important aspects. Was it possible for the participants to pause during listening? Was the text listened to several times? It was not easy to discuss these two aspects, because, in several experiments they examined, these aspects were not accurately described. For example, Meloy, Deville, and Frisbie (2002) obtained a strong effect size ($d = 1.10$, computed by Wood et al.), but in this study, the texts were presented "several times". When reading Meloy et al.'s paper it is difficult to determine what text and what question were presented "several times" and how many is "several".

In another study (Vandenbroucke & Tricot, 2018), researchers investigated the supposed positive effect of oral presentation with long texts, using the kind of text that is frequently presented orally: stories. According to the transient information effect we should obtain a null or negative effect of this oral presentation for every reader, including for students with dyslexia. In a second experiment, we lengthened presentation time, by adding self-paced or system-paced pauses. We compared story comprehension for grade 5 students with or without dyslexia. For each experiment, 20 students with dyslexia were asked to read a story and then to listen to another one (or in reverse, listen first, read after), and 20 students without dyslexia of the same age were asked to do the same. The 40 students with dyslexia (20/experiment) were diagnosed by the disorders unit of a paediatric hospital or by a speech therapist. Diagnostic tests showed no attentional deficit or discrete attentional deficit, no intellectual, oral language, or motor coordination deficits. All students had French as their native language. Two stories (fictional narrative texts) tested by the French Education Ministry for national evaluation of comprehension were used (466 words / sound track 3'52'' for one; 275 words / sound track 2'26'' for the other). In the "reading" condition, there was no time limit. Comprehension questions were presented orally, as were the students' answers which were recorded.

For the first experiment, every student read one text and listened to the other one. For the second experiment, in a test of the spacing effect, every student listened to a text without pauses and listened to the other one with system-paced pauses (each pause was 7 seconds long, one pause after each sentence) or self-paced (the student stopped the sound track whenever she or he wanted). Each participant answered 9 questions immediately after reading or listening: 3 literal comprehension questions (explicit information in the text), 3 local comprehension questions (processing of inferences and relations between different information of the text), and 3 global comprehension questions (the reader needed to use her or his knowledge to understand the whole text). A total score was measured for every text in every condition. Reading time was recorded.

Experiment 1 results showed that whether the text was presented in written or oral form, students with dyslexia obtained lower comprehension scores than those without dyslexia. Oral presentation did not improve comprehension for students with dyslexia (the rate of correct answers was 0.44 in the reading condition and 0.46 in the listening condition). Their reading time was more than twice as long (average = 5’46’’) than the average-level participants with no dyslexia (average = 2’08’’). Reading time for students with dyslexia was longer than listening time, with the opposite result for average-level students. While the transient information effect was not obtained, the students with dyslexia spent much more time reading than listening.

Experiment 2 results showed that students with dyslexia performed better in the system-paced pauses condition, indicating the spacing effect. In this condition, students with dyslexia performed at the same level as students without dyslexia (rate of correct answers = 0.51). In the self-paced pauses condition, students with dyslexia (except 1, out of 10) made no pauses. Unsurprisingly, the rate of correct answers (0.37) was therefore very close to the no-pause condition (0.40). In the self-paced pauses condition, 7 out of 10 students without dyslexia made one or several pauses and their rate of correct answers was far better (average = 0.62) than students with dyslexia. In sum, in the system-paced pauses condition, students with and without dyslexia performed at the same level, although students with dyslexia performed at almost half of the level of students without dyslexia in the self-paced pauses condition.

Time is an important parameter for students with dyslexia. According to Gabrieli (2009), it is the second important source of difficulty for students with dyslexia, with phonological deficit, even for adults. When there is no time limit, adults with dyslexia obtain similar comprehension scores as good readers (Parrila, Georgiou, & Corkett, 2007).

In sum, reducing cognitive load during reading for students with dyslexia is complex. Visual presentations can be improved, but encouraging results must be replicated. It is possible to use oral presentations but the results obtained are contradictory. If time pressure decreases performance, it seems that conversely, increasing time on reading leads to better performance.

CLT May Explain these Diverse Results

Earlier, we indicated several hypotheses generated by CLT intended to increase text comprehension for students with dyslexia. It is difficult to conclude from the examination of the meta-analyses in the domain that these hypotheses can be confirmed or rejected, because these meta-analyses do not control variables such as text length or time spent on reading. The results also confirmed that more time to read, for example, by adding pauses during reading, increased text comprehension but self-paced pauses may be unused by students with dyslexia.

When testing the effects of allowing pauses and allowing multiple opportunities to listen to the text with grade 5 students, we found that listening to text did not improve text comprehension for students with dyslexia. These participants spent more time on reading compared to readers of the same age with no dyslexia. Adding pauses during text listening increased comprehension for students with dyslexia and reduced the difference from other participants. These results suggested that the transient information effect was obtained here (Leahy & Sweller, 2011; Spanjers, Wouters, Van Gog, & Van Merrienboer, 2011), but they also confirmed that time on task was a component of instructional design. This suggestion was supported by a new working memory model that included time as a key resource in working memory (Barrouillet & Camos, 2015). Other CLT effects could be tested in trying to improve text comprehension for students with dyslexia.

Implications for Practitioners

Even if our knowledge in this domain is sketchy, based on the research reviewed thus far, it is possible to consider that students with dyslexia should benefit from:

- Read-aloud presentation of text added to written text, but the benefits are modest and variable.
- Read-aloud presentation of text added to written text with a longer time to process the text, probably based on system-paced pauses.
- Text presentation with spaced letters and words, short lines (even if replications of these recent results are needed).
- General CLT principles for students with low cognitive resources (*i.e.* novices), such as the use of worked examples, the integration of the information (in space and time) that the student will have to link mentally, the elimination of all unnecessary or decorative information.
- Explicit instruction in several domains like vocabulary, text grammar, processing anaphors and making inferences; and also metacognitive strategies like answering questions on the text, self-questioning and self-explaining the text, monitoring and self-evaluating text comprehension; group discussions on the text and reciprocal teaching; re-reading.
- Students with dyslexia may not benefit from the use of spoken presentation of extensive texts instead of written presentations.

The above strategies are likely particularly fruitful for students in mid-elementary school and above. Earlier in elementary school, students with dyslexia (or who are at risk of being identified as dyslexic) should benefit from reinforced training in reading; *e.g.,* morphological training, decoding skills training; phonemic awareness instruction; and, graphosyllabic training. These were discussed earlier in the chapter.

Another recent development in the instructional space that draws heavily on CLT involves Load Reduction Instruction (LRI; Martin, 2016; Martin & Evans, 2018). This promising work places a heavy emphasis on the expertise reversal and guidance fading effects by suggesting that detailed guidance is needed for novices but with increasing expertise, reduced guidance becomes increasingly effective. Furthermore, this work emphasises the importance of motivation, an area that is largely neglected by CLT.

Future Directions

CLT can be used to generate hypotheses and to focus our attention on important variables relevant to the improvement of reading for students with dyslexia. Inconsistent results to date in improving text comprehension for students with dyslexia could be linked to a lack of control of several variables or the need to improve research design. Here are the more important issues going forward.

The transient information effect should be further investigated, sentence length (Rowe, Rowe, & Pollard, 2004), text genre and text length should be controlled. According to CLT, it is possible to hypothesise that substituting spoken for written presentation of texts increases comprehension for students with dyslexia only when the texts are short and simple (Leahy & Sweller, 2011). Long and complex texts should not result in any benefits of additional spoken text. This could be a critical variable in explaining incoherent results in text-to-speech strategies for students with dyslexia.

The modality effect and the redundancy effect should be investigated. When students with dyslexia have to understand a text referring to a map, graph, diagram or tabular information, do they understand better if the text is presented orally? Reciprocally, when they have to understand a text, do they understand better if this text is illustrated by a relevant picture? Do they understand movies as well as students without dyslexia? We need an exhaustive understanding of the Matthew effect (Stanovich, 2009, provided a general view of Matthew effects in reading) in different media (text, pictures, animations, film movies), because poor reading skills may have general negative consequences on learning and we need to know if processing different media produces or decreases these general negative consequences.

The working memory resource depletion effect should be investigated. When students with dyslexia read a text, do their working memory resources deplete? Is this possible depletion comparable to students without dyslexia? Does this possible depletion depend on text length? The effect of pauses during reading and listening should be investigated, but also the effects of facilitating rewinding on electronic spoken texts, re-reading sentences, and decreasing spoken text speed.

Recent extensions of CLT should also be investigated among students with dyslexia. For example, the Load Reduction Instruction Scale (LRIS) has been validated among "typical" students in the "regular" classroom (Martin & Evans, 2018) and students taught by teachers scoring highly on the LRIS are also more motivated, higher achieving, and report less intrinsic and extraneous cognitive load. How do these results generalize to students with dyselexia? Does LRI hold the same promise for these students' academic development as it does for the general ability learners assessed in the Martin and Evans (2018) study? These important questions require additional investigation.

Conclusion

Increasing text comprehension for students with dyslexia is a major issue in the domain of special needs education. Several previous results are encouraging. These include: read-aloud presentation of text added to written text with a longer time to process the text; text presentation with spaced letters and words; short lines; effective instructional principles for students with low cognitive resources (*i.e.* novices); and explicit instruction of linguistic and metacognitive aspects of reading. But also, the results in this area are diverse and sometimes contradictory. Cognitive load theory can be used to explain and investigate this diversity and these contradictions, to generate more acurate and valid results, and to guide practice to increase text comprehension by decreasing the cognitive load involved in reading for students with dyslexia.

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References

American Psychiatric Association (2013). *Diagnostic and statistical manual of mental disorders*, Retrieved from https://www.psychiatry.org/psychiatrists/practice/dsm/dsm-5

Barrouillet, P., & Camos, V. (2015). *Working memory: Loss and reconstruction*. Hove: Psychology Press.

Bianco, M., Pellenq, C., Lambert, E., Bressoux, P., Lima, L., & Doyen, A. L. (2012). Impact of early code skill and oral comprehension training on reading achievement in first grade. *Journal of Research in Reading, 35*, 427-455. doi.org/10.1111/j.1467-9817.2010.01479.x

Boets, B., de Beeck, H.P.O., Vandermosten, M., Scott, S.K., Gillebert, C.R., Mantini, D., & Ghesquière, P. (2013). Intact but less accessible phonetic representations in adults with dyslexia. *Science, 342*, 1251-1254. doi.org/10.1126/science.1244333

British Dyslexia Association (2014). *Dyslexia style guide*. Retrieved from http://www.bdadyslexia.org.uk/common/ckeditor/filemanager/userfiles/About_Us/policies/Dyslexia_Style_Guide.pdf

Cain, K., Oakhill, J., & Bryant, P. (2004). Children's reading comprehension ability: Concurrent prediction by working memory, verbal ability, and component skills. *Journal of Educational Psychology, 96*, 31-42. dx.doi.org/10.1037/0022-0663.96.1.31

Carroll, J.M., & Snowling, M.J. (2004). Language and phonological skills in children at high risk of reading difficulties. *Journal of Child Psychology and Psychiatry, 45*, 631-640. doi.org/10.1111/j.1469-7610.2004.00252.x

Casalis, S., Colé, P., & Sopo, D. (2004). Morphological awareness in developmental dyslexia. *Annals of Dyslexia, 54*, 114-138. doi.org/10.1007/s11881-004-0006-z

Chen, O., Castro-Alonso, J. C., Paas, F., & Sweller, J. (2018). Extending cognitive load theory to incorporate working memory resource depletion: Evidence from the spacing effect. *Educational Psychology Review*, *30*, 483-501. doi.org/10.1007/s10648-017-9426-2

Colé, P., Casalis, S., & Dufayard, C. (2012). *MORPHOREM software*. Retrieved from http://www.orthoedition.com/evaluations/morphorem-705.html

Coltheart, M. (1978). Lexical access in simple reading tasks. In G. Underwood (Ed.), *Strategies of information processing* (pp. 151-216). London: Academic Press.

Cornoldi, C., & Oakhill, J. V. (Eds.). (2013). *Reading comprehension difficulties: Processes and intervention*. New York: Routledge.

Cronbach, L. J., & Snow, R. E. (1977). *Aptitudes and instructional methods: A handbook for research on interactions*. New York: Irvington.

Ecalle, J., Kleinsz, N., & Magnan, A. (2013). Computer-assisted learning in young poor readers: The effect of grapho-syllabic training on the development of word reading and reading comprehension. *Computers in Human Behavior, 29*, 1368-1376. DOI:10.1016/j.chb.2013.01.041

Ehri, L.C., Nunes, S.R., Willows, D.M., Schuster, B.V., Yaghoub-Zadeh, Z., & Shanahan, T. (2001). Phonemic awareness instruction helps children learn to read: Evidence from the National Reading Panel's meta-analysis. *Reading Research Quarterly, 36*, 250-287. dx.doi.org/10.1598/RRQ.36.3.2

Elbeheri, G., & Everatt, J. (2007). Literacy ability and phonological processing skills amongst dyslexic and non-dyslexic speakers of Arabic. *Reading and Writing, 20*, 273-294. DOI 10.1007/s11145-006-9031-0

Evett, L., & Brown, D. (2005). Text formats and web design for visually impaired and dyslexic readers-clear text for all. *Interacting with Computers, 17*, 453-472. doi.org/10.1016/j.intcom.2005.04.001

Fischbach, A., Könen, T., Rietz, C. S., & Hasselhorn, M. (2014). What is not working in working memory of children with literacy disorders? Evidence from a three-year-longitudinal study. *Reading and Writing, 27*, 267-286. doi.org/10.1007/s11145-013-9444-5

Fisher, S. E., & DeFries, J. C. (2002). Developmental dyslexia: Genetic dissection of a complex cognitive trait. *Nature Reviews Neuroscience, 3*, 767-780. doi.org/10.1038/nrn936

Florit, E., & Cain, K. (2011). The simple view of reading: Is it valid for different types of alphabetic orthographies? *Educational Psychology Review, 23*, 553-576. doi.org/10.1007/s10648-011-9175-6

Gabrieli, J. D. (2009). Dyslexia: A new synergy between education and cognitive neuroscience. *Science, 325*, 280-283. doi.org/10.1126/science.1171999.

Gala, N. (2016). *ALECTOR project*. Retrieved from https://www.researchgate.net/project/Reading-Aids-to-leverage-Document-Accessibility-for-Children-with-Dyslexia-ANR-project-2016-2020

Gala, N., & Ziegler, J. (2016) Reducing lexical complexity as a tool to increase text accessibility for children with dyslexia. *Proceedings of the Workshop Computational Linguistics for Linguistic Complexity (LC4LC) at the 26th International Conference on Computational Linguistics* (COLING-2016). Osaka, Japan.

Geary, D. (2008). An evolutionarily informed education science. *Educational Psychologist, 43*, 179-195. doi.org/10.1080/00461520802392133

Geary, D. (2012). Evolutionary educational psychology. In K. Harris, S. Graham, & T. Urdan (Eds.), *APA Educational Psychology Handbook* (Vol. 1, pp. 597-621). Washington: American Psychological Association.

Geary, D., & Berch, D. (2016). Evolution and children's cognitive and academic development. In D. Geary & D. Berch (Eds.), *Evolutionary perspectives on child development and education* (pp. 217-249). Switzerland: Springer.

Gersten, R., Fuchs, L.S., Williams, J.P., & Baker, S. (2001). Teaching reading comprehension strategies to students with learning disabilities: A review of research. *Review of Educational Research, 71*, 279-320. doi.org/10.3102/00346543071002279

Ginns, P. (2005). Meta-analysis of the modality effect. *Learning and Instruction*, *15*, 313-331. dx.doi.org/10.1016/j.learninstruc.2005.07.001

Gough, P.B., & Tunmer, W.E. (1986). Decoding, reading, and reading disability. *Remedial and Special Education, 7*, 6-10. doi.org/10.1177/074193258600700104

Ho, C. S. H., Law, T. P. S., & Ng, P. M. (2000). The phonological deficit hypothesis in Chinese developmental dyslexia. *Reading and Writing, 13*, 57-79. doi.org/10.1023/A:1008040922662

Hodapp, J., Judas, C., Rachow, C., Munn, C., & Dimmitt, S. (2007). *Summary report of the Iowa text reader longitudinal study 2006–2007*. Iowa Assistive Technology Liaisons.

Hook, P.E., Macaruso, P., & Jones, S. (2001). Efficacy of Fast ForWord training on facilitating acquisition of reading skills by children with reading difficulties: A longitudinal study. *Annals of Dyslexia, 51*, 73-96. doi.org/10.1007/s11881-001-0006-1

Hoover, W.A., & Gough, P.B. (1990). The simple view of reading. *Reading and Writing, 2*, 127-160. doi.org/10.1007/BF00401799

Joseph, L.M., Alber-Morgan, S., Cullen, J., & Rouse, C. (2016). The effects of self-questioning on reading comprehension: A literature review. *Reading and Writing Quarterly, 32*, 152-173. doi.org/10.1080/10573569.2014.891449

Kalyuga, S., Ayres, P., Chandler, P., & Sweller, J. (2003). The expertise reversal effect. *Educational Psychologist, 38*, 23-31. doi.org/10.1207/S15326985EP3801_4

Kalyuga, S., Chandler, P., & Sweller, J. (1998). Levels of expertise and instructional design. *Human Factors, 40*, 1-17.

Kalyuga, S., Chandler, P., & Sweller, J. (2004). When redundant on-screen text in multimedia technical instruction can interfere with learning. *Human Factors, 46*, 567-581. doi.org/10.1518/hfes.46.3.567.50405

Kalyuga, S., Chandler, P., Tuovinen, J., & Sweller, J. (2001). When problem solving is superior to studying worked examples. *Journal of Educational Psychology, 93*, 579-588. dx.doi.org/10.1037/0022-0663.93.3.579

Kalyuga, S., & Renkl, A. (Eds.). (2010). Special issue: Expertise reversal effect. *Instructional Science, 38*, 209-323. doi.org/10.1007/s11251-009-9102-0

Kendeou, P., Broek, P., Helder, A., & Karlsson, J. (2014). A cognitive view of reading comprehension: Implications for reading difficulties. *Learning Disabilities Research and Practice, 29*, 10-16. doi.org/10.1111/ldrp.12025

Kirby, J. R., Deacon, S. H., Bowers, P. N., Izenberg, L., Wade-Woolley, L., & Parrila, R. (2012). Children's morphological awareness and reading ability. *Reading and Writing, 25*, 389-410. doi.org/10.1007/s11145-010-9276-5

Landerl, K., Ramus, F., Moll, K., Lyytinen, H., Leppänen, P. H., Lohvansuu, K., & Kunze, S. (2013). Predictors of developmental dyslexia in European orthographies with varying complexity. *Journal of Child Psychology and Psychiatry, 54*, 686-694. doi.org/10.3389/fpsyg.2014.01169

Lazonder, A.W., & Harmsen, R. (2016). Meta-analysis of inquiry-based learning: Effects of guidance. *Review of Educational Research, 86*, 681-718. doi.org/10.3102/0034654315627366

Leahy, W., & Sweller, J. (2011). Cognitive load theory, modality of presentation and the transient information effect. *Applied Cognitive Psychology, 25,* 943-951. doi.org/10.1002/acp.1787

Lee, T.T., & So, W.W. (2015). Inquiry learning in a special education setting: Managing the cognitive loads of intellectually disabled students. *European Journal of Special Needs Education, 30*, 156-172. doi.org/10.1080/08856257.2014.986907

Leikin, M., & Bouskila, O. A. (2004). Expression of syntactic complexity in sentence comprehension: A comparison between dyslexic and regular readers. *Reading and Writing, 17*, 801-822. doi.org/10.1007/s11145-004-2661-1

Lundberg, I., & Olofsson, Å. (1993). Can computer speech support reading comprehension? *Computers in Human Behavior, 9*, 283–293. dx.doi.org/10.1016/0747-5632(93)90012-H

Malstädt, N., Hasselhorn, M., & Lehmann, M. (2012). Free recall behaviour in children with and without spelling impairment: The impact of working memory subcapacities. *Dyslexia, 18*, 187-198. doi.org/10.1002/dys.1446

Martin, A. J. (2016). *Using load reduction instruction (LRI) to boost motivation and engagement*. Leicester, UK: British Psychological Society.

Martin, A. J., & Evans, P. (2018). Load reduction instruction: Exploring a framework that assesses explicit instruction through to independent learning. *Teaching and Teacher Education, 73*, 203-214. doi.org/10.1016/j.tate.2018.03.018

Mastropieri, M.A., & Scruggs, T.E. (1997). Best practices in promoting reading comprehension in students with learning disabilities 1976 to 1996. *Remedial and Special Education, 18*, 198-213. doi.org/10.1177/074193259701800402

McCandliss, B., Beck, I.L., Sandak, R., & Perfetti, C. (2003). Focusing attention on decoding for children with poor reading skills: Design and preliminary tests of the word building intervention. *Scientific Studies of Reading, 7*, 75-104. dx.doi.org/10.1207/S1532799XSSR0701_05

McNamara, D.S., & Magliano, J. (2009). Toward a comprehensive model of comprehension. *Psychology of Learning and Motivation, 51*, 297-384. doi.org/10.1016/S0079-7421(09)51009-2

Meloy, L.L., Deville, C., & Frisbie, D.A. (2002). The effect of a read aloud accommodation on test scores of students with and without a learning disability in reading. *Remedial and Special Education, 23*, 248-255. doi.org/10.1177/07419325020230040801

Murphy, P.K., Wilkinson, I. A., Soter, A.O., Hennessey, M.N., & Alexander, J.F. (2009). Examining the effects of classroom discussion on students' comprehension of text: A meta-analysis. *Journal of Educational Psychology, 101*, 740-764. doi:10.1037/a0015576

Oakhill, J., Cain, K., & Bryant, P.E. (2003). The dissociation of single-word reading and text comprehension: Evidence from component skills. *Language and Cognitive Processes, 18*, 443-468. doi.org/10.1080/01690960344000008

Olson, R. K. (2000). Individual differences in gains from computerassisted remedial reading. *Journal of Experimental Child Psychology, 77*, 197–235. doi.org/10.1006/jecp.1999.2559

Owen, E., & Sweller, J. (1985). What do students learn while solving mathematics problems? *Journal of Educational Psychology, 77*, 272-284. dx.doi.org/10.1037/0022-0663.77.3.272

Parrila, R., Georgiou, G., & Corkett, J. (2007). University students with a significant history of reading difficulties: What is and is not compensated? *Exceptionality Education International, 17*, 195-220.

Potocki, A., Magnan, A., & Ecalle, J. (2015). Computerized trainings in four groups of struggling readers: Specific effects on word reading and comprehension. *Research in Developmental Disabilities, 45*, 83-92. doi.org/10.1016/j.ridd.2015.07.016

Ramus, F. (2014). Neuroimaging sheds new light on the phonological deficit in dyslexia. *Trends in Cognitive Sciences, 18*, 274-275. doi.org/10.1016/j.tics.2014.01.009

Ramus, F., & Ahissar, M. (2012). Developmental dyslexia: The difficulties of interpreting poor performance, and the importance of normal performance. *Cognitive Neuropsychology, 29*, 104-122. doi.org/10.1080/02643294.2012.677420

Ramus, F., & Szenkovits, G. (2008). What phonological deficit? *The Quarterly Journal of Experimental Psychology, 6*1, 129-141. doi.org/10.1080/17470210701508822

Roussel, S. (2011). A computer assisted method to track listening strategies in second language learning. *ReCALL, 23*, 98-116. doi.org/10.1017/S0958344011000036

Rowe, K., Rowe, K., & Pollard, J. (2004). *'Literacy Behaviour'and auditory processing: Building 'fences' at the top of the 'cliff' in preference to ambulance services at the bottom.* https://research.acer.edu.au/research_conference_2004/6

Scammacca, N., Roberts, G., Vaughn, S., Edmonds, M., Wexler, J., Reutebuch, C. K., & Torgesen, J. K. (2007). *Interventions for adolescent struggling readers: A meta-analysis with implications for practice*. Portsmouth: RMC Research Corporation, Center on Instruction.

Schiavo, G., & Buson, V. (2014). Interactive e-Books to support reading skills in dyslexia. *IBOOC2014, 2nd Workshop on Interactive eBook for Children*, IDC'14, June 17–20, Aarhus, Denmark.

Schneps, M. H., Thomson, J. M., Sonnert, G., Pomplun, M., Chen, C., & Heffner-Wong, A. (2013). Shorter lines facilitate reading in those who struggle. *PloS one, 8*, e71161. doi.org/10.1371/journal.pone.0071161

Schüler, A., Scheiter, K., & Gerjets, P. (2013). Is spoken text always better? Investigating the modality and redundancy effect with longer text presentation. *Computers in Human Behavior, 29*, 1590-1601. doi.org/10.1016/j.chb.2013.01.047

Snowling, M.J. (2013). Early identification and interventions for dyslexia: A contemporary view. *Journal of Research in Special Educational Needs, 13*, 7-14. doi.org/10.1111/j.1471-3802.2012.01262.x

Snowling, M.J., Gallagher, A., & Frith, U. (2003). Family risk of dyslexia is continuous: Individual differences in the precursors of reading skill. *Child Development, 74*, 358-373. doi.org/10.1111/1467-8624.7402003

Snowling, M.J., & Hulme, C. (2013). Children's reading impairments: From theory to practice. *Japanese Psychological Research, 55*, 186-202. doi.org/10.1111/j.1468-5884.2012.00541.x

Spanjers, I.A., Wouters, P., Van Gog, T., & Van Merrienboer, J.J. (2011). An expertise reversal effect of segmentation in learning from animated worked-out examples. *Computers in Human Behavior, 27*, 46-52. doi.org/10.1016/j.chb.2010.05.011

Stanovich, K. E. (2009). Matthew effects in reading: Some consequences of individual differences in the acquisition of literacy. *Journal of Education, 189*, 23-55. doi.org/10.1177/0022057409189001-204

Sweller, J. (2010). Element interactivity and intrinsic, extraneous and germane cognitive load. *Educational Psychology Review, 22*, 123-138. doi.org/10.1007/s10648-010-9128-5

Sweller, J. (2015). In academe, what is learned, and how is it learned? *Current Directions in Psychological Science, 24*, 190-194. doi.org/10.1177/0963721415569570

Sweller, J. (2016). Story of a research program. *Education Review//Reseñas Educativas, 23*. Retrieved from http://edrev.asu.edu/index.php/ER/article/view/2025

Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive load theory*. New York: Springer.

Sweller, J., & Cooper, G.A. (1985). The use of worked examples as a substitute for problem solving in learning algebra. *Cognition and Instruction, 2*, 59-89. doi.org/10.1207/s1532690xci0201_3

Tallal, P., Merzenich, M.M., Miller, S., & Jenkins, W. (1998). Language learning impairments: Integrating basic science, technology, and remediation. *Experimental Brain Research, 123*, 210-219. doi.org/10.1007/s002210050563

Therrien, W. J. (2004). Fluency and comprehension gains as a result of repeated reading: A meta-analysis. *Remedial and Special Education, 25*, 252-261. doi.org/10.1177/07419325040250040801

Tobias, S. (1976). Achievement treatment interactions. *Review of Educational Research, 46*, 61-74. doi.org/10.3102/00346543046001061

Torgesen, J.K., Alexander, A.W., Wagner, R.K., Rashotte, C.A., Voeller, K.K., & Conway, T. (2001). Intensive remedial instruction for children with severe reading disabilities: Immediate and long-term outcomes from two instructional approaches. *Journal of Learning Disabilities, 34*, 33-58. doi.org/10.1177/002221940103400104

Tricot, A., & Sweller, J. (2014). Domain-specific knowledge and why teaching generic skills does not work. *Educational Psychology Review, 26*, 265-283. doi.org/10.1007/s10648-013-9243-1

Tyler, J. M., & Burns, K. C. (2008). After depletion: The replenishment of the self's regulatory resources. *Self and Identity, 7*, 305-321. doi.org/10.1080/15298860701799997

Vandenbroucke, G., & Tricot, A., (2018). La présentation orale de textes narratifs améliore-t-elle la compréhension d'élèves dyslexiques de CM2? [Is spoken presentation of stories increases comprehension for grade 5 students with dyslexia?] *Analyse Neuropsychologique des Apprentissages chez l'Enfant*, *152*, 111-121.

Van den Broek, P., & Kremer, K.E. (2000). The mind in action: What it means to comprehend during reading. In. B.M. Taylor, M.F. Graves & P. van den Broek (Eds.), *Reading for meaning: Fostering comprehension in the middle grades* (pp. 1-31). New York: Teachers College Press.

Van den Broek, P., Kendeou, P., Kremer, K., Lynch, J.S., Butler, J., White, M.J., & Lorch, E.P. (2005). Assessment of comprehension abilities in young children. In S. Stahl & S. Paris (Eds.), *Children's reading comprehension and assessment* (pp.107-130). Mahwah: Erlbaum.

Van Dijk, T.A., & Kintsch, W. (1983). *Strategies of discourse comprehension*. New York: Academic Press.

Vellutino, F.R., Fletcher, J.M., Snowling, M.J., & Scanlon, D.M. (2004). Specific reading disability (dyslexia): What have we learned in the past four decades? *Journal of Child Psychology and Psychiatry, 45*, 2-40. doi.org/10.1046/j.0021-9630.2003.00305.x

Vellutino, F.R., Tunmer, W.E., Jaccard, J.J., & Chen, R. (2007). Components of reading ability: Multivariate evidence for a convergent skills model of reading development. *Scientific Studies of Reading, 11*, 3-32. doi.org/10.1207/s1532799xssr1101_2

Wong, A., Leahy, W., Marcus, N., & Sweller, J. (2012). Cognitive load theory, the transient information effect and e-learning. *Learning and Instruction, 22*, 449-457. doi.org/10.1016/j.learninstruc.2012.05.004

Wood, S. G., Moxley, J. H., Tighe, E. L., & Wagner, R. K. (2017). Does use of text-to-speech and related read-aloud tools improve reading comprehension for students with reading disabilities? A meta-analysis. *Journal of Learning Disabilities, 51*, 73-84. doi.org/10.1177/0022219416688170

World Health Organization (2016). *International statistical classication of diseases and related health problems – ICD-10*. Retrieved from http://www.who.int/classifications/en/

Ziegler, J.C., & Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory. *Psychological Bulletin, 131*, 3-29. doi.org/10.1037/0033-2909.131.1.3

Zorzi, M., Barbiero, C., Facoetti, A., Lonciari, I., Carrozzi, M., Montico, M., & Ziegler, J.C. (2012). Extra-large letter spacing improves reading in dyslexia. *Proceedings of the National Academy of Sciences, 109*, 11455-11459. doi.org/10.1073/pnas.1205566109.