Digital Natives With Reading Difficulties

A study of dyslexic adolescents' integration of conflicting information across web pages and presentation formats

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Ode on Working Memory

There once was a box called short-term store
Whose function was storage and nothing more.
But along came Alan Baddeley
Whose subjects dual-tasked madly
And WM replaced STS forevermore.

For those who've been living in caves
Working memory is a system with slaves.
They are independent buffers
So that neither one suffers
When doing verbal memory with visual maze.

While storage is the job of each little slave
The central executive says how we behave.
From up in the prefrontal lobes
It activates and controls all nodes
Through a dopamine system acting as gates.

The unanswered questions on WM abound
Despite numerous studies whose findings are sound.
What's needed right now
Is for us to see how
We can put all these data on common ground.

- Janice Keenan (1999)

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Abstract

The new literacies of online reading place new demands on student readers as their reading materials have expanded from textbooks to different representations and sources on the Internet. This requires digital literacy, which is not an innate skill. Rather, readers have to learn how to construct their own reading paths and integrate often contradictory information across web pages and presentation formats into a coherent whole. While this can lead to deeper learning, little is known about how these new demands may affect struggling readers. Therefore, a main aim of this thesis was to investigate possible differences between typical and struggling readers on how they manage the integration demands in multimedia learning. In the first paper we describe a quantitative study comparing students with and without dyslexia (N = 44) on a multiple source integration task. In this study we found that participants without dyslexia clearly outperformed participants with dyslexia on the integration task. Further, observed differences with respect to multiple source integration were largely due to working memory differences between the two groups. The second paper, which describes a multiple case study, investigates differences within the dyslexic group (N = 4) on the same tasks as in the first paper. This study found that, in addition to differences in reading speed and comprehension, participants' different processing patterns could be related to outcomes on post reading knowledge and integration tasks. As the demands of digital literacy are assumed to draw heavily on working memory, the thesis also reviews how working memory has been conceptualized in contemporary research on multimedia learning that uses cognitive load theory as the major theoretical framework, and how subjective measures have been used in this research. Accordingly, the findings of the third paper showed that most of the reviewed studies did not include any conceptualization or clear definition of working memory, used only general subjective measures containing one or very few items, and did not report

findings consistent with the hypothesized relationship between cognitive load and multimedia learning.

Papers I – III

Paper I

Andresen, A., Anmarkrud, Ø., Bråten, I. (in press). Investigating Multiple Source Use among Students with and without Dyslexi**a.** *Reading and Writing*,1–26. doi: https://doi.org/10.1007/s11145-018-9904-z

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Paper II

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Paper III

Anmarkrud, Ø., Andresen, A., & Bråten, I. (submitted). Cognitive Load and Working Memory in Multimedia Learning: Conceptual and Measurement Issues

Status: Resubmitted to Educational Psychologist August 27, 2018

Note: These papers are provided after the extended abstract in this thesis

Table of contents

Table of figures and tables

PART I:

Theoretical framework, method and summaries of papers

1. Introduction

1.1 Background and purpose

We live in a world where the Internet has become *the* defining technology for literacy and learning, and where literacy changes every day due to the emergence of new information technologies, such as Skype, Facebook, and Instagram (Leu, Kinzer, Coiro, Castek, & Henry, 2013). A very high proportion of adolescents, at least in the Western world, have access to and use the Internet both for school related activities and in their spare time. According to the Pew Center for Internet and American Life, 93% of American 12-17 year olds use the Internet (Center for the Digital Future, 2016; Pew Research Center, 2009), and in Norway this figure is equally high with 90% of Norwegians aged between 16 and 79 using the Internet on a daily basis in 2017 (Statistics Norway, 2018). Today's readers, including those with dyslexia, have access to a wide variety of information sources through the Internet, such as texts, videos, animations, audio files, pictures, and interactive tables. Not only do they have access to these types of information, they are also expected to use them for school and homework assignments and when making decisions about different aspects of their daily life (Cho & Afflerbach, 2015; Goldman et al., 2010; Scharrer, Bromme, Britt, & Stadtler, 2012; Stadtler & Bromme, 2013).

However, Internet reading is often complex, and reading and learning in the 21th century require new and sophisticated skills, among others source evaluation and integration of information across sources and formats, such as pictures, videos, sound and text (Alexander & The Disciplined Reading and Learning Research Laboratory, 2012; Braasch, Bråten, Strømsø, Anmarkrud, & Ferguson, 2013; Braasch et al., 2009; Bråten, Britt, Strømsø, & Rouet, 2011; Goldman, Braasch, Wiley, Graesser, & Brodowinska, 2012; Goldman & Scardamalia, 2013; Leu et al., 2013; Rouet, 2006; Sandoval, Greene, & Bråten, 2016). Accordingly, constructing meaning in an online environment requires accomplished readers with sophisticated strategies and high reading competency (Cho & Afflerbach, 2015; Leu et al., 2013). This has led researchers to introduce terms such as digital literacy (Greene, Copeland, Deekens, & Yu, 2017) and new literacy (Leu et al., 2013) to distinguish online reading and comprehension from traditional reading of text on paper. In addition to the skills mentioned above, readers must be able to "realize and construct potential texts", that is, construct their own reading paths and decide which texts to read according to their information needs (Cho & Afflerbach, 2015). Research shows that students are not always capable of meeting these requirements of literacy in the 21th century (Anmarkrud, Bråten, &

Strømsø, 2014; Cho & Afflerbach, 2015; Greene, Yu, & Copeland, 2014; Greene et al., 2017). As stated by Greene et al. (2017), the required skills are not innate but have to be taught. Further, reading in an online environment might be even more challenging for readers with dyslexia than for typically developing readers. Specifically, the combined requirements of high working memory capacity and adequate word decoding skills, which presumably characterize learning on the Internet (Barsky & Bar-Ilan, 2012; DeStefano & LeFevre, 2007; Rosman, Mayer, & Krampen, 2016), could lead to cognitive overload for this group of readers (Anmarkrud, Brante, & Andresen, 2018; Gathercole, Alloway, Willis, & Adams, 2006; Melby-Lervåg, Lyster, & Hulme, 2012). Still, research is very limited on readers with dyslexia reading in an online environment. Thus far, research on dyslexia has focused mostly on decoding problems as a consequence of phonological difficulties, and research on learning on the Internet has to a very little degree focused on experiences of readers with dyslexia using the Internet for school purposes and in their spare time. The research on students with dyslexia in an online environment has so far mostly focused on a dyslexia friendly interface (e.g., Borg, Lantz, & Gulliksen, 2015; McCarthy & Swierenga, 2010), and online technology and tools that can contribute to literacy development for students with dyslexia (e.g., Feeney, 2003; Harrison, 2012). To address this gap in extant research, this thesis represents an attempt to integrate research on dyslexia and research on learning from multiple representations on the Internet, that is, multimedia learning.

A main purpose of this thesis is to investigate possible differences between typical and struggling readers with respect to how they learn and integrate information from conflicting web based sources about a socio-scientific issue. Also, it focuses on individual difference variables that might impact the outcome of such web based, multimedia learning. The first research questions addressed in this thesis therefore concern possible differences between readers with and without dyslexia when working in a new literacy context:

1a) To what extent do students with and without dyslexia differ with respect to learning from and integrating information across different web pages and representations when working with conflicting information about a controversial socio-scientific issue?

1b) Can likely differences in integration of information across web pages and representations between the two groups of students be explained in terms of differences between the two groups with respect to word recognition, working memory, or both?

Second, as will be elaborated in the subsequent theoretical discussion of dyslexia, dyslexia is not a clear cut diagnosis (Elliott & Grigorenko, 2014; Snowling & Melby-Lervåg, 2016). Therefore, in a group of students with dyslexia, there likely are relatively good readers as well as readers at the low end of the continuum, even when compared to other students with dyslexia. Thus, large differences in processing patterns, processing time, decoding skills, and working memory between the best and the poorest dyslexic readers might be expected. Such differences could be contributing factors to performance differences within the dyslexic group with respect to multimedia learning. Therefore this thesis also asks:

2a) To what extent are there variations in processing patterns among students with dyslexia when reading multimodal information on different web pages and to what extent do these processing patterns represent deliberate, strategic activity?

2b) How are processing patterns related to individual differences among participants and to their learning from and integration of multimodal information presented on different web pages?

Third, because cognitive load and, consequentially, demands on working memory may be high in multimedia learning contexts (see Section 2.2.2), and because students with dyslexia often suffer working memory deficits in addition to having word-level difficulties (Fischbach, Könen, Rietz, & Hasselhorn, 2014; Gathercole et al., 2006; McLoughlin, Fitzgibbon, & Young, 1994; Menghini, Finzi, Carlesimo, & Vicari, 2011; Smith-Spark & Fisk, 2007; Swanson & Jerman, 2007), the need to integrate information across different representations and sites can be expected to produce cognitive overload for this group of readers (Chan & Unsworth, 2011). In order to design instructions and multimedia learning materials that may help preventing cognitive overload in learners, including students with dyslexia, it is important to use reliable and valid measures of cognitive load during multimedia learning. An investigation into issues concerning the measurement of cognitive load is therefore relevant to this thesis. Accordingly, the following questions are addressed:

3a) How is working memory conceptualized in contemporary cognitive load research on multimedia learning, and to what degree is working memory assessed in this research?
3b) How are subjective measures of cognitive load used in this research, and are subjective measures combined with other measures of cognitive load?
3c) How are the results from subjective measures of cognitive load related to learning

and achievement?

1.2 Outline of the thesis

The main body of Part I of the thesis presents and discusses relevant theoretical assumptions and prior research, the methodological approach and design issues, and summaries of the three papers included in Part II. Specifically, Part I Section 2 presents theory on learning from single versus multiple sources and on multimedia learning, including theory on two important perspectives on multimedia learning: working memory and multimedia learning, and multimedia learning and cognitive load. Section 2 continues with a discussion of dyslexia, including theoretical assumptions regarding possible effects of dyslexia on multimedia learning. In this section, I attempt to give an overview of the main theoretical concepts rather than providing an in depth discussion. In Section 3 the methods and research designs used in the thesis are presented. Section 4 contains summaries of the three papers included in the thesis, and in Section 5 of Part I, discussions of main findings and limitations and suggestions for future research are presented before educational and theoretical implications are presented and discussed.

Study I is a comparative quantitative study, Study II is a mixed methods multiple case study, and Study III is a systematic review regarding measurement of cognitive load in multimedia contexts.

2 Theoretical background and prior research

The multimedia digital age puts new demands on readers (Castek, Zawilinski, McVerry, O'Byrne, & Leu, 2011). For example, searching the Internet for information about different topics has become increasingly common. In addition, the multiplicity of written sources encountered both in and out of school makes it important not only to understand single texts but to be able to integrate information from multiple sources (e.g., Kammerer, Meier, & Stahl, 2016; Kingsley & Tancock, 2014; Mason, Junyent, & Tornatora, 2014; Van Strien, Brand-Gruwel, & Boshuizen, 2014). Typically learning from web based sources also requires integration of information across different representations, such as text and pictures, audio files and videos, etc.

2.1 Learning from single versus multiple sources

2.1.1 Learning from single sources

Comprehending single texts involves the construction of coherent mental models of textual content. Kintsch's (1988) construction-integration model is one of the most influential models explaining the comprehension of single texts. According to Kintsch, knowledge is organized as associative networks with network nodes consisting of concepts and propositions (Kintsch, 1998). During reading, a part of the network is activated, and it is this activated part of the knowledge network that is at work during the construction of text based meaning (Anmarkrud, 2009). Further, the model explains reading comprehension as a result of two main processes: the construction process and the integration process (Graesser, 2007).

The construction process starts with representing the concepts and propositions directly corresponding to the linguistic input. Then, a small number of the most closely associated neighbors from the associative network are activated and certain additional propositions are inferred, before connection strengths are assigned to all pairs of elements that have been activated (Kintsch, 1988). The result is an initial textbase representation. As this textbase representation can be both incoherent and contradictory, the integration phase involves the integration of the text base with the reader's knowledge such that irrelevant information is eliminated and the reader can form a coherent mental representation, a situation model, that merges text-based information with information residing in long term memory (i.e., prior knowledge) (Cho, 2014).

Thus, when comprehending text, representations are constructed at several levels: the reader is assumed to construct a surface code, a textbase, and a situation model (Kintsch, 1988). The surface code preserves the exact wording and syntax of textual sentences, the textbase is an encapsulated representation of what the text says based on the reader's decoding and understanding of words and sentences in the text, and the situation model is an elaboration based on an integration of the meaning of the text itself and prior knowledge (Stadtler & Bromme, 2013).

For example, if a sentence reads: "Peter was so long in the sun, his face looked like a tomato", the explicit propositions of the text are "Peter was in the sun" and "Peter's face looked like a tomato". This is the meaning of the text at microstructure level. The reader then uses words such as *so*, *because*, *however*, to make inferences in order to understand the main idea of the sentences. In this case the word *so* would help the reader "bridge the gap" between the two parts of the sentence. Also, in addition to the explicit propositions, the reader makes implicit propositions based on prior knowledge. In this case, these propositions would lead the reader to the interpretation that it was the fact that he stayed in the sun so long that made Peter's face so red that it looked like a tomato (i.e., the reader knows that 1) staying long in the sun can cause sun burn, 2) sun burn makes your skin red, and 3) tomatoes are red). According to Kintsch's model, a text is well understood when the different levels of textual representations are well integrated (Anmarkrud, 2009).

2.1.2 Learning from multiple sources

To explain how readers understand multiple texts about the same situation or issue, Britt, Perfetti, Sandak, and Rouet (1999) proposed the documents model, which is an extension of Kintsch's (1988) construction-integration model. Understanding multiple texts requires students to integrate information across documents and construct a coherent mental representation. According to Britt et al. (1999), the added complexity of understanding multiple compared to single texts requires the combination of cross-text content integration and attention to source information (i.e., information about the origin of texts, such as their authors), a combination that they try to capture by adding an integrated mental model and an intertext model to Kintsch's model (Britt & Rouet, 2012). The integrated mental model refers to the integrated and overarching understanding of the situation described across documents. The intertext model includes links between source information and content information as well as links between different sources (Britt et al., 1999). Thus, the intertext model represents readers' knowledge about "who says what" (i.e., source-content links) as well as their knowledge about how different sources are related (e.g., that Author A contradicts Author B). These source-content links and source-source links in combination with the mental model are assumed to constitute a full documents model that makes coherent understanding possible even when conflicting claims or perspectives are presented in different documents (Anmarkrud, Bråten, & Strømsø, 2014). In essence, then, the documents model explains how good readers may build a coherent mental representation of a topic from content presented across multiple documents and, at the same time, keep sources apart (Britt & Rouet, 2005).

The documents model of Britt et al, (1999), although resulting from research on the comprehension of multiple texts, also informs understanding of the complex use of reading strategies required when reading on the Internet (Cho, 2014). Imagine a grade 10 student who uses the Internet to learn about sunbathing and health for a home assignment. She accesses three web pages with partly contradictory views on the issue. One page contains the information that sunbathing is healthy, another argues for the harmful effects of sunbathing, and yet another presents neutral, factual information about ultraviolet radiation. Each page contains a video or infographic, a picture, and a text. Hence, the student has to process the information from the various representations (picture, text, and video) and the three different pages, select information that is relevant for the task she is currently working on, evaluate and organize the selected information, and finally integrate these pieces of information with each other and with prior knowledge residing in long-term memory. If this leads to a coherent mental representation of the situation described across pages and representations, where she also tags content information for the respective sources and understands the relationships among different sources, she has succeeded in building a full documents model.

2.2 Multimedia learning

The building of a mental model based on materials that consist of both verbal and pictorial representations, that is, an integrated understanding of text and graphics, is described by Mayer (2005a) as multimedia learning. Research indicates that "under certain circumstances people learn more deeply from words and pictures than from words alone" (Mayer, 2005a, p.6). Under such circumstances, dual coding (verbal and visual) makes successful retrieval more likely, such that text information is remembered better with than without illustrations (Mayer, 2005a; Mayer, Heiser, & Lonn, 2001). The underlying idea is that each modality (form of sensory perception) is a delivery system for information, and that it is better to have two deliveries of the same information than just one (Mayer et al., 2001). This is called the multimedia effect (Mayer, 2005a). For instance Butcher (2006), in a study of learning from text with different diagrams, found that diagrams supported integration of information during learning. Also, Ainsworth (1999), in a literature review on the functions of multiple representations, argued that multiple representations can be beneficial if translations across representations are supported. In line with these research findings, Schnotz, Picard, and Hron (1993), in a study of possible differences between successful and unsuccessful learners with regard to the use of texts and graphics, found that if the user is able to successfully map information between graphics and mental models, "the use of graphics can have a strong influence on learning success" (p. 196). Section 2.2.1.2 contains a more thorough presentation of research findings in support of Mayer's model of multimedia learning.

2.2.1 Models of multimedia learning

2.2.1.1 Mayer's model

Several cognitive models have been developed to explain multimedia learning. Mayer's (2001; Mayer & Moreno, 2010) cognitive theory of multimedia learning (CTML) and Schnotz and Bannert's (Schnotz, 2005; Schnotz & Bannert, 2003) integrated model of text and picture comprehension (ITPC) are two of the most influential. Although there are differences between these two models, they both assume a cognitive system with multiple memory stores where a working memory system of limited capacity is the central processing component. According to both models, good multimedia learning requires the integration of information from various presentation formats (e.g., text, pictures, videos, interactive graphs, and so forth), and they both posit that learning from multimedia can be hampered by the constraints of the cognitive system, in particular by working memory constraints. [1]

Mayer's cognitive theory of multimedia learning, in particular, defines multimedia learning as the building of mental representations based on the selection of relevant information. Further, Mayer (1997) posited that meaningful learning requires learners to integrate newly built representations with other familiar structures already stored in memory. His theory is based on three principles: 1) the *dual channel assumption*, 2) the *limited capacity assumption* and 3) the *active processing assumption*.

First, the *dual channel assumption* posits that different channels exist for visual (pictorial) and auditory or verbal processing. This assumption is based on the dual coding theory of Paivio (1986). According to Paivio (1986), verbal associations and visual imagery are handled cognitively by separate subsystems along channels in the human mind "which are assumed to be structurally and functionally distinct" (p. 54). Thus, the nonverbal and verbal symbolic systems can be active in parallel or one system can be active without the other (Paivio, 1986). Although they are seen as separate systems, they are also considered interconnected so that one system can trigger activity in the other that is assumed to lead to deeper learning because it is likely to lead to two mental representations interconnected via referential connections (Paivio, 1986; Schüler, Arndt, & Scheiter, 2015).

Second, the *limited capacity assumption* posits that each of these two channels has a limited capacity for processing. This means that learners can only process a few pieces of information actively (usually five to seven chunks) at a time in each channel (Baddeley, 2000; Clark & Mayer, 2008; Swanson & Alloway, 2012).

Finally, the *active processing assumption* posits that learning is an active process of filtering, selecting, organizing, and integrating information based upon prior knowledge, specifically that the verbal representations and the pictorial representations have to be

[1] See Section 2.2.4 for a more elaborated presentation of working memory

integrated (Mayer, 2005b). Graphics and text are usually processed through the visual channel (the eyes) and spoken words are processed through the auditory channel (the ears). After information cues are selected through these channels, the learner can associate new information with the mental models already residing in long term memory (Clark & Mayer, 2008).

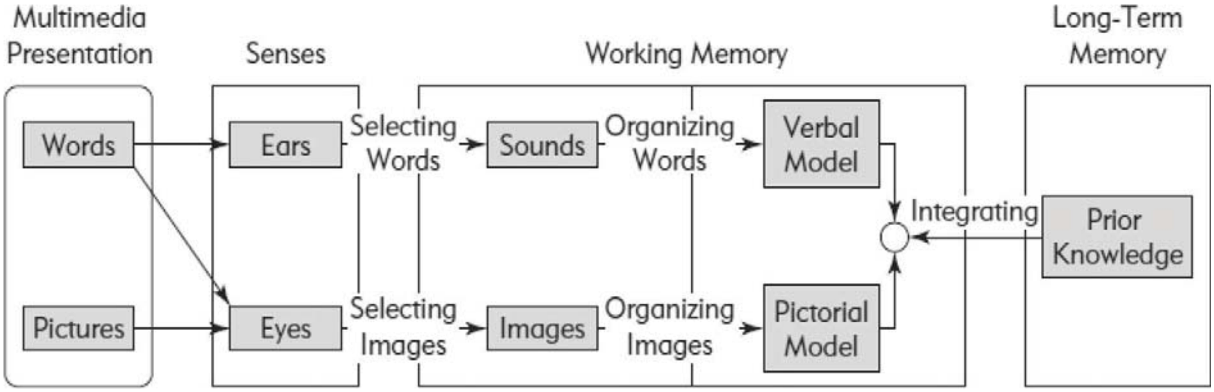

Figure 1 The cognitive theory of multimedia learning (Clark & Mayer, 2008)

According to the cognitive theory of multimedia learning (see Figure 1), there are five cognitive processes in multimedia learning. These five processes are: "*selecting* relevant words from the presented text or narration, *selecting* relevant images from the presented graphics, *organizing* the selected words into a coherent verbal representation, *organizing* selected images into a coherent pictorial representation, and integrating the pictorial and verbal representations and prior knowledge" (Mayer, 2005b, p. 43). These five processes occur in three steps. The first step is *selecting* relevant aspects of visual and verbal information from the sense receptors for processing in the pictorial and verbal parts of working memory. The next step is to *organize* the selected material by transforming verbal knowledge within the verbal part of working memory and visual knowledge within the pictorial part of working memory (Mayer, 2008). The final step is to connect the organized verbal and pictorial information to each other and to other familiar knowledge structures already in memory. This, according to Mayer's model, is called *integrating* (Mayer, 2008). For the integration process to take place, the visual and verbal information must be held in working memory. However, the capacity of working memory for holding information is limited, which means that integrating visual and verbal information during learning is constrained by memory load (Mayer, 1997).

Mayer's theory is motivated by the idea that research on how people learn should be the basis for design of instructional materials (Mayer, 1997). The rationale behind the multimedia principle is to take advantage of the full capacity of human information processing. According to Mayer (2005a), the process of trying to build connections between words and pictures may help learners create a deeper understanding than from words or pictures alone; however, simply adding pictures to words is not sufficient, the design of materials must build upon knowledge of how people learn, as discussed above (Mayer, 2005a).

2.2.1.2 Research findings in support of Mayer's model

Mayer and Anderson (1992) conducted a study in which college students learned about the operation of a bicycle tire pump. The instruction was based on a) animation, b) animation with concurrent oral narration, c) only animation, or d) only narration. A control condition with no instruction was also included in the study. It was found that the learners who had access to animation with concurrent oral narration performed better than the other groups. In line with this finding, Mayer, Steinhoff, Bower, and Mars (1995) compared problem solving among two groups; one group (called the integrated group) viewed a visual presentation depicting the major stages in the formation of lightning that (a) were placed adjacent to corresponding text paragraphs on one page, and (b) contained labels and captions repeating the verbal cause-and-effect information from the text), and the other group (separated group) viewed the same illustration: a) on another page and b) without labels and captions, after finishing reading the text. The integrated group generated more creative transfer problem solutions than the separated group. Further, the positive effects depended on incorporating labels and captions into the illustrations rather than placing illustrations close to corresponding paragraphs. These findings have been replicated several times. For example, a similar experiment was conducted with college students who read about the formation of lightning, where one group read a summary that contained short captions with illustrations of the main steps of lightning and another group read the full text with such a visual summary, or the full text alone. This study by Mayer, Bove, Bryman, Mars, and Tapangco (1996) found that students learned more effectively when words and illustrations were presented together rather than separately. Further, Mayer and colleagues have conducted several other studies on the multimedia effect, among those, eight studies which investigated problem solving transfer when students received a verbal explanation coordinated with a visual explanation compared to a verbal explanation only (Mayer, 1997). Each of these comparisons showed that adding a visual explanation to a verbal one greatly enhanced students' understanding.

2.2.1.3 *Schnotz and Bannert's integrated model of text and picture comprehension*

Schnotz and Bannert's (2003) integrated model of text and picture comprehension (ITPC) maintains that there are two basic forms of representations - depictions and descriptions - and that these are "fundamentally different" (p.144). Examples of depictive representations are pictures and physical models, whereas descriptions can be for instance text and mathematical equations containing signs for relations. According to the model, human cognitive architecture consists of modality-specific sensory registers, working memory and long term memory, and the model encompasses listening comprehension, visual picture comprehension, and what Schnotz and Bannert call "auditory picture comprehension", which refers to the comprehension of sound (Schnotz, 2005).

According to Schnotz and Bannert (2003), learning from depictions and descriptions requires the construction of multiple mental representations through organization of information, parsing of symbol structures, and mapping of analog structures, as well as model construction and model inspection (Schnotz & Bannert, 2003, 141). Specifically, the model assumes that the reader of a text constructs a mental representation of the text surface structure and generates a propositional representation of the semantic content (i.e., a textbase). The reader then constructs a mental model of the subject matter from the textbase, which resembles Kintsch's (e.g. 1998) situation model (Schnotz & Bannert, 2003; Schüler, Arndt, & Scheiter, 2015). In picture comprehension, the individual first creates a visual mental representation of the picture's graphic display through perceptual processing. Then he or she constructs a mental model and also a propositional representation of the content of the picture through semantic processing (Schnotz & Bannert, 2003). Both in text comprehension and in picture comprehension, there is a continuous interaction between the propositional representation and the mental model, via processes of model construction and model inspection guided by cognitive schemata (Schnotz & Bannert, 2003, p 146). Further, comprehension requires learners to build coherent knowledge structures from the external verbal and pictorial information and from prior knowledge.

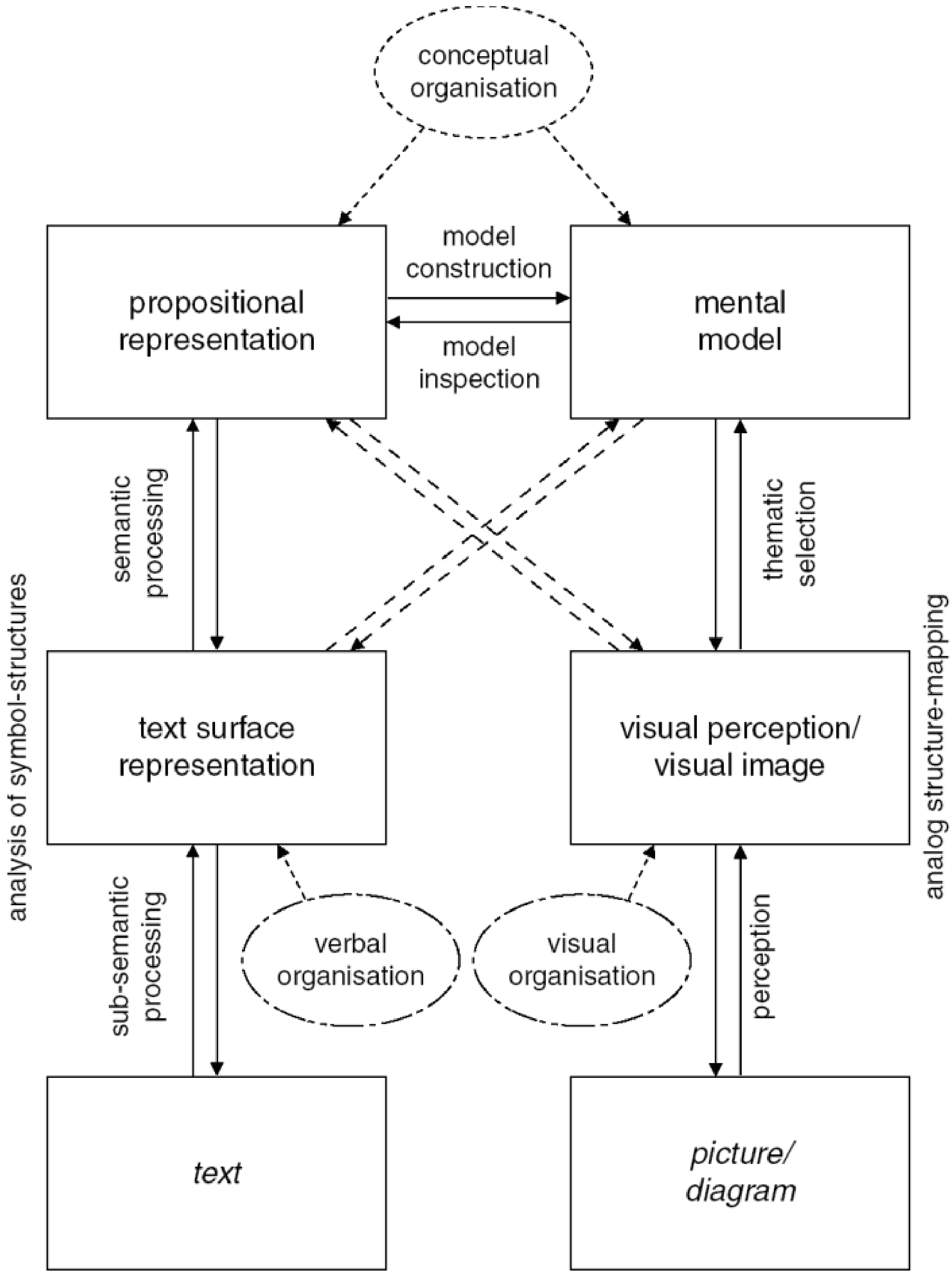

Figure 2 Schnotz and Bannert's integrated model of text and picture comprehension (Schnotz & Bannert (2003)

To sum up, Mayer's Cognitive Theory of Multimedia Learning and Schnotz and Bannert's integrated model of text and picture comprehension both posit that integration of text and pictures is a requirement for succeeding in multimedia learning. However, whereas Mayer's model assumes that learners build one-to-one correspondences between the verbal and the pictorial mental representation, and that learners construct two mental models (verbal and pictorial) that have to be integrated, Schnotz and Bannert (2003) posit that texts and pictures use different sign systems resulting in fundamentally different forms of representations, but that learners construct *one* mental model which integrates information from different sources.

2.2.2 Cognitive demands of multimedia learning

As described above, for successful multimedia learning to occur, learners have to integrate information from verbal representations (spoken or written text) and information from pictorial representations, both static (e.g., drawings, photos, graphs) and dynamic (e.g., animations and videos), into a coherent understanding of the issue in question (Mayer, 2005a). This is considered to be cognitively demanding, because the amount of information the learner has to keep in working memory to be able to integrate information across sources and formats can lead to cognitive overload (Anmarkrud et al. 2014; Chan & Unsworth, 2011; Gil, Bråten, Vidal-Abarca, & Strømsø, 2010; Hagen, Strømsø, & Bråten, 2009; Hartman, Morsink, & Zheng, 2010; Kamil & Chou, 2009; Maggioni & Fox, 2009;Tabachnek, Leonardo, & Simon, 1997, Cho, 2014; Unsworth & Chan, 2008). Research shows that students do not always succeed in this integration.

For instance, Chan and Unsworth (2011) in a study of Grade 6 students reading in a multimedia environment found that students may experience difficulties in integrating complementary meanings from image and text and also in constructing coherent meaning by means of bridging inferences. According to those authors, the development of such skills requires that educators support young students when learning in multimedia environments. Moreover, Cho (2014), in a study of accomplished readers' Internet reading strategies, found that those readers modified and iterated traditional reading strategies used during print-based reading (e.g., meaning-making, information evaluation, and self-monitoring), and that they used such strategies in combination with Internet-specific strategies (e.g., text location). Likewise, Anmarkrud et al.'s (2014) study of strategic processing during the reading of multiple documents identified the strategies of meaning-making, information evaluation, and self-monitoring, which contributed to undergraduate readers' successful learning from multiple sources in a digital text environment. Further, Goldman et al., (2012) posited that for readers to succeed in Internet reading, they have to compare a variety of digital sources in an effective way and also make informed choices regarding which sources to read and how to sequence their reading of those sources. Also, they must decide when and where to read further and whether they should access additional sources or not.

2.2.3 Design principles within multimedia learning

As discussed above, multimedia learning is cognitively demanding in general. In addition, not all multimedia designs are equally effective (Mayer, 2001). Mayer et al. (2001) defined some principles within multimedia learning to explain why multimedia in some cases can be detrimental for learning. Two of these principles are the spatial contiguity principle and the redundancy principle. The spatial contiguity principle states that meaningful learning from multimedia is more likely to occur when corresponding words and pictures are presented near each other instead of far from each other. If the spatial contiguity principle is violated, learners will have to remember information while for instance turning to another page or scrolling, which will increase the demands on working memory (Mayer & Fiorella, 2005; Schnotz & Kürschner, 2007).

According to the redundancy principle, learning materials should not combine text and pictures for learners for whom one of the representations is sufficient to build an adequate mental representation. This is because the redundant information requires mental effort without enhancing learning (e.g., Mayer et al., 2001; Moreno & Mayer, 2002). Both the spatial contiguity and the redundancy principle may be moderated by learners' prior knowledge and expertise. For example, Kalyuga, Chandler, and Sweller (1998) found that learners with high expertise in a field did not need text-based information to be physically integrated with a diagram, and even experienced reduced cognitive load when the text was eliminated. Hence, these principles may be especially relevant for less knowledgeable learners or struggling readers.

Although it is an open question whether the integration of information from different channels results in two interconnected mental representations or one single representation merging information from text and pictures (Schüler et al., 2015), there is agreement that learning from multimedia involves the integration of information from text and pictures into a coherent representation, and that this can be assumed to be more cognitively challenging than reading a single text in print because it draws heavily on the capacity of working memory. Working memory can thus be considered a bottleneck in multimedia learning.

2.2.4 Working memory and multimedia learning

Working memory is a much studied construct which first appeared in research in the 1960s but has undergone a lot of investigation and consequent changes since then. There has been disagreement among researchers about what constitutes working memory, however (Shah & Miyake, 1999). Two examples of controversies were the question of whether working memory is a unitary or non-unitary construct, and the question of working memory limitations, especially regarding which mechanisms constrain working memory capacity (Shah & Miyake, 1999). In recent years working memory as a system involving both storage and processing has replaced the notion of a passive short-term storage system, and there seems to be agreement among prominent researchers in the field that working memory is a cognitive resource involved in the storage of information accessed either through the senses or from long term memory, while simultaneously manipulating information for brief periods of time (Alloway, 2009; Baddeley & Logie, 1999; Swanson & Alloway, 2012). As such, working memory is considered to play an essential role in cognitive tasks (Baddeley & Logie, 1999; Shah & Miyake, 1999).

Further, Baddeley (2000) stated that the Baddeley and Hitch working memory model from 1974 left the idea of "a short-term memory (STM) that was assumed to comprise a unitary temporary storage system" (p. 418), and argued for a multi-component system. Also, this model highlighted the function of this system in complex cognition instead of memory per se. In other words Baddeley's conceptualization of working memory assumes the existence of multiple specialized components and assigns working memory an essential role in complex cognitive activities. This view is supported by Miyake and Shah (1999, p.450), positing that working memory can be defined as "those mechanisms or processes that are involved in the control, regulation, and active maintenance of task-relevant information in the service of complex cognition, including novel as well as familiar skilled tasks".

2.2.5 Baddeley's model of working memory

Baddeley's model is one of the most influential models of working memory (Baddeley, 1986, 1999, 2000; Badeley & Logie, 1992), and several multimedia learning theories are based on this model (Mayer, 2005b; Schüler, Scheiter, & van Genuchten, 2011). In this thesis I therefore use Baddeley's model as the framework for understanding working memory in relation to multimedia learning. Baddeley (2000, p. 418) defined working memory as "a limited capacity system allowing the temporary storage and manipulation of information necessary for such complex tasks as comprehension, learning and reasoning". According to an early version of Baddeley's model, which went through a major extension in 2000, working memory consists of three specialized components for processing different kinds of content: the central executive, the phonological loop, and the visuospatial sketchpad (Baddeley, 1986). The episodic buffer was added to the model in 2000 (Baddeley, 2000).

The phonological loop is specialized for processing and temporary maintenance of verbally coded information. The phonological loop consists of a phonological store and a rehearsal system. The phonological store is the passive storage unit of the phonological loop where spoken words enter directly, whereas the rehearsal system is involved in the conversion of written words from a visual to an articulatory code before the words are transferred to the phonological store (Baddeley & Logie, 1999; Schüler, Scheiter, & Genuchten, 2011). The visuospatial sketchpad is specialized for processing and temporary storage of visual and spatial information, for instance shape, color, and movements, and it forms an interface between these two kinds of information, accessed through the senses or from long term memory (Baddeley & Logie, 1999; Baddeley, 2001; Schüler et al., 2011).

These two so-called slave systems (i.e., the phonological loop and the visuospatial sketchpad) function as short-term storage centers. The third component, the central executive, works as an attentional control system responsible for the coordination of the two slave systems and for regulating and updating working memory contents, but it is not assumed to have the capacity to store information in different codes (Schüler et al., 2011). Hence, the original model did not take into consideration the need to integrate information from the subsidiary systems and from long-term memory in a way that makes maintenance and manipulation possible (Baddeley, 2001, p. 14). However, research by Baddeley et al. (2000, 2001, 1984, 1993) showed that patients with limitations in short term phonological memory could still recall more digits with visual presentation, raising the question of where and how these digits are stored. Further, patients with limitations in short term memory but an intact long term memory had a lower sentence span than one would normally expect, which suggests that chunking is not a purely long term memory phenomenon. These findings revealed a need for an explanation of the fact that there seems to be a "temporary back-up store" "that is capable of supporting serial recall, and presumably of integrating phonological, visual, and possibly other types of information" (Baddeley, 2000, p 419). Further this temporary store also seems capable of holding complex information over a much longer time than assumed possible for the slave systems of working memory. Later, Baddeley therefore labeled this temporary store the episodic buffer, and this was added to his working memory model (Baddeley, 2000). He (2000, p. 421) defined the episodic buffer as "a limited-capacity temporary storage system that is capable of integrating information from a variety of sources" (Baddeley, 2000, p.421). The term episodic buffer implies that it is able to hold what Baddeley calls "integrated scenes or episodes" and the buffer is an interface of limited capacity between systems using different codes (Baddeley, 2001, p. 14).

2.2.6 Multimedia Learning and Cognitive Load

Cognitive load theory (Chandler & Sweller, 1991) deals with the implications of working memory limitations for multimedia learning. The theory highlights that when working memory capacity is exceeded, the result is cognitive overload. Cognitive load theory has become important for the design and evaluation of instruction, presumably due to the growing use and importance of multimedia representations in school and everyday life (Schnotz & Kürschner, 2007). Cognitive load theory defines cognitive load as "a multidimensional construct representing the load that performing a particular task imposes on the learner's cognitive system" (Paas, Tuovinen, Tabbers, & Van Gerven, 2003, p. 64). Cognitive load theory can be considered a learning and instruction theory (Sweller, Ayres, & Kalyuga, 2011), according to which it is important to free working memory capacity for learning by reducing unnecessary cognitive load. To be able to design instructions that comply with this aim, knowledge of the human cognitive architecture, such as the characteristics of and intricate relations between working memory and long-term memory, is crucial (Paas & Sweller, 2005). More specifically, when designing instruction, the limited capacity of working memory should be taken into consideration to avoid cognitive overload (Kalyuga, 2011; Leppink, Paas, Van Gog, van der Vleuten, & van Merriënboer, 2013). According to Paas and Sweller (2005), working memory has limitations both with regard to how much information can be processed, and with regard to the duration of content, that is, with regard to how long information can be kept. As multimedia learning requires processing, storing, and integration of information, and is therefore assumed to impose a heavy load on working memory, cognitive load theory is a relevant theory in multimedia learning (Brunken, Plass & Leutner, 2003).

Cognitive load theory further assumes that learning tasks can impose three different kinds of cognitive load: intrinsic, extraneous, and germane load. Originally the main concern in cognitive load theory was to suggest ways to reduce extraneous cognitive load in learning (Sweller, 1988). Extraneous load arises if information is presented in a way that is suboptimal for learning because the instructional activities are cognitively too demanding. For instance one could assume that in order to learn how to perform a statistical operation using a specific software, it will be easier to watch a video of a person performing the analysis step by step than to receive a verbal explanation, because one will be able to see where to click and how the screen is supposed to look during the process and when the operation is finished. Hence, one might reduce extraneous load by displaying operations in this way instead of having students read an instruction.

The concept of extraneous cognitive load was later supplemented with the concept of intrinsic cognitive load because there were unexplained empirical findings that demanded an additional concept (Kalyuga, 2011). Intrinsic load is associated with the load that is determined by the number of interacting information elements in the learning task or materials, in other words by the complexity and structure of the materials (Ayres, 2006). The concept of intrinsic load was added because experiments had shown that for instance split attention and redundancy effects were not demonstrated when the complexity of the learning task or material was low (Kalyuga, 2011). In cognitive load theory, intrinsic load is traditionally regarded as related to the nature of the learning task and the level of learner expertise. For instance if a struggling reader needs to process and connect pieces of information from different sources on the Internet in order to construct a coherent mental representation of an issue, this can generate a particularly high level of intrinsic cognitive load for this reader. Presumably, both the high element interactivity characterizing the task and the load imposed by decoding could create problems for struggling readers in such task contexts.

Finally, germane cognitive load was added to cognitive load theory to indicate the load placed on working memory during schema formation and automation, that is, when relating relevant information from long-term memory to new information elements (Ayres, 2006; Sweller, 2010; Sweller et al., 2011). Germane cognitive load was introduced because it had become increasingly clear that cognitive load did not always interfere with learning but was also necessary for learning. No learning will occur without cognitive processing and associated working memory load. Recently, there has been some discussion around the concept of germane cognitive load, however (Kalyuga, 2011; Sweller 2010). Since germane cognitive load arises from relating relevant information from long-term memory to new information elements (Sweller, 2010; Sweller et al., 2011), it pertains to the working memory resources allocated to dealing with intrinsic cognitive load, and can therefore be considered "good" load, as opposed to "bad" extraneous load (Kalyuga, 2011; Sweller, 2010). It could therefore be argued that one should use the term *germane resources* instead of the term germane load (Kalyuga, 2011).

In brief, cognitive load theory argues that the way instructions are designed has a strong influence on learning outcome and that knowledge about human cognitive architecture, in particular working memory limitations, is essential to make instructions as effective as possible. Of course, this does not imply that there is a one-to-one- relation between learning instruction and learning outcome, because learners' prior knowledge and domain expertise also play important roles (Opfermann, Scheiter, Gerjets, & Schmeck, 2013). Therefore, in designing instructions one should also take differences in learners' expertise and possible learning difficulties into consideration.

2.2.7 Advantages and disadvantages of learning in multimedia environments

2.2.7.1 Advantages

As discussed in Section 2.2, the principles of multimedia learning are based on the premise that learning from text and pictures can be more effective than learning from text alone. Also, multimedia learning environments are typically structured in less linear ways than are traditional text reading environments. On an Internet page, for example, readers can choose to look at a picture first before reading the text, or the other way around, and they can go back and forth between pages and representations in the order they choose, which may be beneficial for learning (Opfermann, Scheiter, Gerjets, & Schmeck, 2013). Research (Eitel, Scheitel, & Schüler, 2013; Mason et al., 2017) has shown that depending on the complexity of the information included in the different representations, a brief inspection of pictures before processing textual material sometimes can promote comprehension. This approach is called picture-to-text processing (Eitel, Scheitel, & Schüler, 2013; Mason et al., 2017). In other instances processing text first (text-to-picture processing) may be helpful (Hegarty & Just, 1993). Research also has suggested that the least complex information should be presented first (Eitel & Scheiter 2015; Mason et al., 2017). Because readers in multimedia environments to some extent can construct their own texts by using suitable reading strategies (Cho, 2014; Cho & Afflerbach, 2017), higher engagement and motivation may follow due to enhanced reader control (Scheiter & Gerjets, 2007). Also, the Internet often provides useful tools such as search features and the ability to bookmark and organize text according to learners' own needs. Accordingly, Cho and Afflerbach (2015) found that successful readers working on a complex Internet reading task used advantages allowed for by the Internet to realize and construct their own texts and reading paths, which included exploring web sites relevant to the topic, monitoring reading to avoid getting “lost”, and rejecting texts that turned out to be less relevant.

2.2.7.2 Disadvantages

Although multimedia may have several advantages for learning, there is also a substantial body of research failing to demonstrate positive outcomes. In an extensive review, Scheiter and Gerjets (2007) identified several possible reasons for the ambiguity of results, arguing that the same features of digital environments that can promote learning may also be detrimental. For example, information represented in different ways has to be integrated by the learner. Previous work on the integration of verbal and visual information when reading traditional texts has shown that such integration can be challenging (Chan & Unsworth, 2011), and there are indications that meaning-making in multimedia reading environments poses even greater processing demands on the reader (Chan & Unsworth, 2011; Hartman, Morsink, & Zheng, 2010; Kamil & Chou, 2009), in particular on their working memory resources (DeStefano & LeFevre, 2007; Rosman, Mayer, & Krampen, 2016).

Also, the previously mentioned affordance to construct the reading texts is not always an advantage. It can also be detrimental for readers because it requires a higher degree of expertise and proficiency to avoid “getting lost” (Cho, Woodward, Li, & Barlow, 2017). Another issue is that not all pictures are equally effective. Rather, their effectiveness may depend on how they are incorporated with words and whether the design principles of the spatial contiguity and split attention are followed (Ayres & Sweller, 2005; Mayer & Fiorella, 2005). Further, research has found that interesting but not relevant information may lead to poorer learning (Mayer, 2001; Schnotz, 2005), as may the existence of redundant information. In the latter case, learners will have to process more than one source without gaining an increased understanding of the issue (Kalyuga & Sweller, 2005; Moreno & Mayer, 2002; Schnotz, 2005). In brief, then, while multimedia learning can represent unique opportunities for learning, it can also challenge learners’ working-memory capacity in various ways (Kalyuga, 2007; Scheiter & Gerjets, 2007). In order to design instruction that takes differences in prior knowledge and expertise into consideration and draws on principles for organizing multimedia learning materials to reduce processing demands, it is important to have reliable and valid measures of the cognitive load learners experience during multimedia learning.

2.2.8 Assessing Cognitive Load

As explained in Section 2.2.6, cognitive load is a complex, multidimensional construct. Not surprisingly, then, measuring cognitive load has turned out to be a challenge for researchers because of this complexity (Paas, Tuovinen, Tabbers, & Van Gerven, 2003). While cognitive load has been assessed by indirect measures, such as time on task or errors (Sweller et al., 2011), the use of more direct, subjective measures is currently one of the most common approaches (de Jong, 2010; Naismith, Cheung, Ringsted, & Cavalcanti, 2015; Naismith & Cavalcanti, 2015).

Naismith et al, (2015) recently conducted a systematic review of cognitive load measures, finding that 34 of the 48 studies they reviewed used subjective measures of cognitive load. This finding corroborated findings from previous reviews of the literature (e.g., Paas et al., 2003). Subjective measures of cognitive load are based on the assumption that people are capable of assessing their own mental effort, and these measures typically involve asking participants to rate their cognitive load on one or more items using Likert-type scales. Among the subjective measures of cognitive load, the Paas scale (1992) of mental effort has been most used and cited (Naismith & Cavalcanti, 2015). On this scale, participants rate their mental effort ”by translating the perceived amount of mental effort into a numerical value from very, very low mental effort (1) to very, very high mental effort (9)” (Paas, 1992, p. 430).

Although subjective measures seem to be the most frequently used measures of cognitive load, there are challenges regarding this kind of measurement. For instance, although Paas’ (1992) measure appears to be able to assess learners’ subjective perception of invested effort in a reliable way (Paas, 1992; Paas & van Merriënboer, 1994; Paas, van Merriënboer, & Adam, 1994), it is still unclear how this perceived mental effort relates to actual cognitive load. Also, more recent studies of cognitive load using subjective measures have been criticized for not reporting reliability or sensitivity data (Naismith & Cavalcanti, 2015; Naismith et al., 2015). Another issue concerns construct validity. Thus, different terms (or constructs) have been used in operationalizations of cognitive load. Two examples are the constructs of *perceived difficulty* and *mental effort*, which both have been used in research without any clarification of the difference between them (de Jong, 2010). Other examples of operationalizations are *pressure during task* (Cheng, Lu, & Yang, 2015), *mental load* (Chen & Wu, 2015), *frustration* (Huang et al., 2015), and *mental demand* (Kizilcec, Bailenson, & Gomez, 2015). It is difficult to interpret findings when there is a lack of consistency in how cognitive load has been operationalized in subjective measures. Also, the assumption that participants are able to correctly rate their own cognitive load could be questioned (Hsu, Gao, Liu, & Sweller, 2015; Park, 2015).

Such critique could be met in future research by combining subjective measures with other types of measures. There is, for example, a recently expanding body of literature using physiological measures of cognitive load (Paas, Ayres, & Pachman, 2008; Sweller et al., 2011). In any case, there seems to be a need for more specific measures and a more precise operationalization of cognitive load to increase the precision of results concerning the effects of instructional design on learners' outcome.

2.3 Dyslexia

Developmental dyslexia (hereby referred to as dyslexia) is assumed to be a neurodevelopmental disorder which is relatively common, affecting 3-7% of the population (Hulme & Snowling, 2009, Snowling & Melby-Lervåg, 2016). It is one of the most studied and well-known developmental disorders, characterized by poor spelling and reading in the absence of sensory or neurological damage, and not considered to be caused by inadequate educational opportunities (Ziegler & Goswami, 2005). However, research so far has not been able to reach consensus about what constitutes dyslexia. Thus, there are no clear diagnostic criteria or cut off points, and the definition has changed over the years (Elliott & Grigorenko, 2014; Snowling & Melby-Lervåg, 2016). Moreover, some research has questioned the assumption that dyslexia is neurodevelopmental due to missing evidence of obvious neurological abnormality in individuals with dyslexia (Protopapas & Parrila, 2018).

In the search for a definition of dyslexia, the condition has been distinguished both by the use of a cut-off point criterion and by a discrepancy criterion. The cut-off point criterion posits that students with dyslexia fall below a certain point on reading tests, typically 1.5 standard deviation below the mean (Peterson & Pennington, 2012; Snowling, 2013). The discrepancy criterion implies that children with dyslexia have reading skills below what is expected based on their scores on non-verbal IQ measures (Snowling & Hulme, 2012), consistent with the formerly used definition from the fourth edition of the Diagnostic and Statistical Manual of Mental Disorders: *"…reading achievement […] is substantially below that expected given the person's chronological age, measured intelligence and age-appropriate education"* (American Psychiatric Association, 2004). However, what researchers regard as the lower endpoint of "normal" IQ varies between one or two standard deviations below the mean, which means that this criterion may lead to huge variations in whether IQ will be seen as an exclusionary factor and, consequentially, in whether a child will be classified as dyslexic (Elliot & Grigorenko, 2014). This also means that the discrepancy criterion may lead to a delay in identification and instruction. Further, research has indicated that IQ does not distinguish poor readers who will benefit from intervention from those who will not (Elliot & Grigorenko, 2014). Many researchers therefore have argued that the discrepancy criterion "has outlived its usefulness" (Lyon, Shaywitz, & Shaywitz, 2003, p.8). Accordingly, the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (American Psychiatric Association, 2013) does not refer to a discrepancy criterion as a basis for diagnosis (Snowling, 2013). Currently, one of the most prominent definitions of dyslexia is that of Lyon et al. (2003, p. 2) according to which:

> *Dyslexia is a specific learning disability that is neurobiological in origin. It is characterized by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities. These difficulties typically result from a deficit in the phonological component of language that is often unexpected in relation to other cognitive abilities and the provision of effective classroom instruction.*

As can be seen, diagnosis according to this definition requires that difficulties are unexpected given the cognitive abilities of the person, but there is no mention of measured intelligence. Also, with regard to the "unexpectedness", Shaywitz (2003) has suggested that it "should be assessed via comparisons of reading age with chronological age and/or by comparing reading ability to educational level and professional level of attainment" (p. 133).

Further, during the last decades, the prevailing view of dyslexia in alphabetic languages has been that it is caused by difficulties with the decoding part of reading and that poor phonological awareness is related to these difficulties (Boets et al., 2010; Caravolas et al., 2013; Snowling & Hulme, 2012; Ziegler & Goswami, 2005). Also, dyslexia is typically seen as a complex and heterogeneous condition, and an outcome of multiple risk factors. For example, a long-standing finding in dyslexia research is that many children with reading difficulties experience deficits in the ability to rapidly name familiar items, such as letters, numbers and colors, so called rapid automatized naming (RAN) (Elliot & Grigorenko, 2014), suggesting that difficulties with RAN may be one underlying cause of dyslexia. However, there are probably several contributing factors in dyslexia. Further, the outcome of a risk of dyslexia in a child is also dependent on risk factors or protective factors in the child's environment (Snowling & Melby-Lervåg, 2016).

Although the majority of research on dyslexia has focused on the phonological difficulties that create severe problems in decoding, and on how these difficulties can hamper the development of proficient reading and, consequently, reading comprehension, working memory has also been considered to distinguish between better and poorer readers (Gathercole et al, 2006; McLoughlin, Fitzgibbon, & Young, 1994; Swanson & Berninger, 1995; Swanson & Jerman, 2007).

2.3.1 Research on working memory in relation to dyslexia

Research has supported the hypothesis that less skilled readers suffer working memory deficits, and that this contributes to comprehension problems, independent of their problems in phonological coding. For example, Swanson and Jerman (2007), in a study of reading growth in children with reading disabilities, found working memory to be a predictor of growth in reading comprehension, and in a study of working memory in children with reading disabilities, Gathercole et al. (2006) found that working memory represented an important constraint in reading. Further, according to McLoughlin et al. (1994), inefficient working memory (specifically a deficit in phonological memory) is related to poor reading development.

In addition to deficits in the phonological loop, which is expected based on the phonological difficulties, working memory deficits in readers with dyslexia have been found in the visuospatial modalities (Fischbach, Könen, Rietz, & Hasselhorn, 2014; Menghini, Finzi, Carlesimo, & Vicari, 2011; Smith-Spark & Fisk, 2007). Further, Smith-Spark and Fisk (2007), in a study of working memory functioning in students with dyslexia, found that university students with dyslexia had significantly lower “spatial complex spans” (requiring both storage and processing) than had students in a control group. This suggests a central executive impairment in dyslexia since working memory span tasks involve a simultaneous processing demand that draws on the central executive as well as on the relevant slave system (Smith-Spark & Fisk, 2007). Support for a central-executive impairment was also found in a study by Fischbach et al. (2014), indicating low backward spans among children with literacy disorders.

Finally, Carretti, Borella, Cornoldi, and De Beni (2009) conducted a meta-analysis of 18 studies which examined learners ranging from 7 to 30 years of age, with the purpose of evaluating the extent to which working memory could explain specific reading comprehension difficulties. They found that working memory tasks with high demand of attentional control, which also required verbal processing, differentiated good and poor comprehenders.

2.3.2 Dyslexia and multimedia learning – specific challenges and potential benefits

2.3.2.1 Specific challenges

Because multimedia learning can be considered to place high demands on learners' working memory, it seems likely that multimedia learning can be more challenging for readers with dyslexia than for typically developing readers. Although it has been argued that learning via the Internet could be beneficial for struggling readers because online reading is supported by video clips, pictures, and audio clips (Scheiter & Gerjets, 2007), research also has indicated that integrating information from different representations on the Internet may induce an increased load on working memory. The split attention principle may be particularly relevant for readers with dyslexia in such contexts. When having to split their attention between two or more sources in a multimedia learning environment, cognitive overload may be experienced due to limitations in working memory capacity. In addition, readers with dyslexia will most likely experience higher processing demands in multimedia learning contexts due to poor word reading skills.

However, there seems to be a limited research base on dyslexic readers' multimedia learning. The few existing studies on dyslexic or struggling readers' online reading have mostly focused on the learning outcomes of Internet reading (Castek, Zawilinski, McVerry, O'Byrne, & Leu, 2011) and dyslexia-friendly interfaces (Berget, Mulvey, & Sandnes, 2016; McCarthy & Swierenga, 2010). These studies have indicated that struggling readers may master the technical aspects of multimedia learning but still have pronounced problems with comprehension-related skills such as source awareness and the ability to synthesize information across different sites and presentation formats (Castek et al., 2011).

Some recent research has also supported the idea that multimedia learning could be less effective for readers with dyslexia than for typically developing readers (Anmarkrud, Brante, & Andresen, 2018; Beacham & Alty, 2006; Brante, Olander, & Nyström, 2013). For instance Brante et al. (2013) found that the inclusion of pictures in the learning material hampered dyslexic students' comprehension, and Beacham and Alty (2006) found that dyslexic students' performance in a text only condition was better than when graphs were included in the learning material. However, as elaborated in the following section, research has also indicated that multimedia formats can be beneficial for some readers with dyslexia (Castek et al., 2011).

2.3.2.2 Potential benefits

A study by Castek et al. (2011) focusing on the opportunities and challenges for struggling readers in an Internet environment, found that some struggling readers performed surprisingly well when reading online. Apart from using support from video and pictures, these readers were good at accessing digital features that supported their reading and used search engines effectively, such that they read the search results instead of just clicking on and scanning them. Although these activities were time consuming, they helped readers make informed choices about what to read more carefully.

Also, Henry, Castek, O'Byrne, and Zawilinski (2012) and Castek et al. (2011) have suggested that support from images, videos, and audio files can benefit struggling readers learning in a multimedia environment. This suggestion was supported by Knoop-van Campen, Segers, and Verhoeven (2018), who studied the modality effect (the assumption that learning gain is larger when verbal input is presented auditorily than as text), and the redundancy effect, for children with dyslexia learning in a multimedia environment. These authors found that children with dyslexia spent more time learning in a text condition than in both audio and text-and-audio conditions. Hence, according to this study, audio support could be beneficial for children with dyslexia.

Further, other research findings have suggested that a technology-based reading environment, such as the Internet, may be more engaging for struggling readers: "both as a compensatory tool, providing access to text; and as a learning tool, helping students learn how to read with understanding'' (Dalton & Strangman 2006, p. 75). This view was supported by Leu et al. (2008), who studied instruction and assessment within new literacies and found that students were more motivated for literacy activities when working on the Internet (Leu et al., 2008).

Yet another advantage of online reading may be that it often requires reading shorter text units than does offline reading. This may be considered an advantage for readers with dyslexia, not least motivationally. Also, on the Internet readers often construct their own texts in the sense that they choose which links to follow to find the information they seek. This, according to Castek et al. (2011), may make struggling readers more engaged during reading. Also, the Internet affords such advantages as larger or more reader friendly font sizes and spell check programs which can be a great advantage to struggling readers. However, in order to promote learning in multiple source multimedia contexts for both typically developing and struggling readers, it is important to gain more knowledge about how different groups of readers learn from different sources and representations. Accordingly, the present thesis aims to investigate differences between readers with and without dyslexia as well as differences among readers with dyslexia with regard to learning from multiple information sources and representations.

2.4 Summary

Working memory is considered a limited-capacity system comprised of multiple components that allows for temporary preservation of information and simultaneous processing of the same or other information (Swanson & Berninger, 1995). Further, Baddeley's (2000) model and other models defining working memory as consisting of different subcomponents may seem especially well suited to explain multimedia learning, because, as stated by Kintsch, Healy, Hegarty, Pennington, & Salthouse (1999, p. 425): "complex tasks like multimedia learning involve the coordination of different working memory subcomponents". The usefulness of working memory theories in research on multimedia learning is also supported by Baddeley (1999, p. 417), arguing that his model focuses on "the processes of integrating information". Likewise Schüler et al. (2011) contend that "theories of multimedia learning are based on Baddeley's working memory model" (p. 389).

Moreover, because working memory can be considered to play a central role in the processing of multimedia content, limited working memory capacity, as often found among readers with dyslexia, could hinder successful multimedia learning depending on which of the sub systems are affected by the resource limitation (i.e., limitations in the phonological loop may affect processing of verbal information and limitations in the visuospatial sketchpad will affect processing of pictorial information). Also, since the episodic buffer is considered a storage system for integration of information from several sources, limitations in the episodic buffer could have a negative effect on the integration of verbal and pictorial information. Accordingly, a reduction of working memory load could facilitate multimedia learning, which may be particularly important for readers with dyslexia.

Baddeley's (2000) model also has been linked more specifically to multimedia learning in that two of the assumptions in his model, the assumption of a distinction between a verbal and a visuo-spatial subsystem and the assumption of limited resources, have been incorporated into the theory of multimedia learning (Mayer, 2001) and cognitive load theory (Schüler et al., 2011). Likewise, Schnotz and Bannert's (2003) integrated model of text and picture comprehension explains multimedia learning. Finally, multimedia learning entails certain features that could be of both advantage and disadvantage for typically developing as well as for struggling readers. However, thus far there seems to be a very limited research base on how dyslexic readers cope with these features.

3 Methods and research design

Two of the studies in this thesis are empirical studies, one comparative quantitative study and one multiple case mixed methods study. The third study is a systematic review of research studies published between 2014 and 2017 on multimedia learning that uses cognitive load theory as the major theoretical framework. In this section the methods used in the studies are presented and discussed before ethical considerations as well as reliability and validity issues are discussed. Methodological issues pertaining to the two empirical studies are discussed first, followed by a discussion of the methodology of the systematic review study.

3.1 Methods and research design in the empirical part

3.1.1 The Multiple Case Study Design

Study II applies a comparative case study design (Yin, 2014) based on the triangulation of both quantitative and qualitative data sources described below. Each of the four cases have been analyzed independently, before the final comparison and contrasting of the cases (Campbell, 2012; Yin, 2014).

3.1.2 Mixed methods approach

Mixing of methods can be useful in research to give a more complete understanding of the research findings. Cresswell (2015, p. 2) defines mixed methods as follows:

> *An approach to research in the social, behavioral, and health sciences in which the investigator gathers both quantitative (closed-ended) and qualitative (open-ended) data, integrates the two and then draws interpretations based on the combined strengths of both sets of data to understand research problems*.

In other words, simply having different sources of data is not enough, there has to be some integration between the methods. Also, the rationale behind using a mixed methods approach is that the combination of the different perspectives should produce findings that are greater than the sum of parts (Bazeley & Kemp, 2012; Wooley, 2009).

3.1.2.1 A convergent design

According to Cresswell's (2015) terminology, a convergent design is a design with separate but parallel collection of both quantitative and qualitative data, and distinct analysis, and where the two databases are then merged to compare the results.

The quantitative data in the mixed methods study (Study II) consist of eye tracking data, multiple choice questionnaire data, data based on oral integration questions, and scores on standardized tests. The qualitative data are based on retrospective verbal reports cued by eye tracking recordings. These quantitative and qualitative data were gathered at the same time point (in a single point design) and the results of the data analyses were merged. Further, the results of the quantitative and qualitative data analyses have been compared and discussed after the analyses. This design was chosen to be able to "see the picture from different angles", i.e. to obtain both a quantitative picture and also a more in depth personal perspective of the issue. One of the questions that arise from this design is the sample size for the two datasets (Cresswell 2015). In this study the sample is an identical concurrent sample which means that the sample for the two data sets are the same and have the same size.

Although mixing of methods is increasingly recognized as an approach to strengthen a research study, an issue of concern to researchers using a mixed methods design is how to integrate the different methods (Bazeley & Kemp, 2012; Yin, 2006). The next section will describe how integration was achieved in this research.

3.1.2.2 Argument for mixing of methods

The reason for using a mixed methods design is that quantitative and qualitative data together presumably would give a more complete understanding of the issue than would only one type of data. We used both quantitative measures (eye tracking, multiple choice questionnaires and results from standardized tests and two oral integrative questions), and one qualitative measure (retrospective reports) and integrated the findings from these measures to gain a more complete understanding of the participants' processing and integration of information in the multimedia learning task.

One example of how quantitative and qualitative data were integrated in this research is that qualitative data derived from cued retrospective verbal reports of processing were combined and integrated with quantitative and objective data from eye tracking in the multiple case study. While cued retrospective reports may reveal important information about the content of the cognitive processes, eye fixation data may provide insights into processing demands and inform on the allocation of attention to specific task components, which is difficult to obtain from cued retrospective reports alone. However, eye tracking data alone may also be regarded as insufficient. This is because such data require a great deal of inferencing on the part of the researcher, and it is not possible on the basis of eye tracking data alone to assess the extent to which participants understand what is processed. Using a combination of eye movement data, retrospective verbal reports, and learning and integration outcome measures may therefore reduce the need for inferences and lead to more valid conclusions than using only one of these measures (Kok & Jarodzka, 2017).

3.1.3 Participants in the two empirical studies

The participants in study I were 44 tenth-grade students between 15.8 and 16.6 years of age, 22 boys and 22 girls. The participants attended 10 different public lower secondary schools in southeast Norway. Of these, 22 (16 boys and 6 girls) had been diagnosed with dyslexia after assessment by the school psychology services, with diagnosis based on severe difficulties with single word decoding and phonological processing (Lyon et al., 2003). The remaining 22 students (6 boys and 16 girls) did not display any dyslexic symptoms, all scoring above the 20th percentile on a national standardized reading test (The Norwegian Directorate for Education and Training, 2017). These non-dyslexic students constituted a comparison group matched with the dyslexia group for age. We chose the 20^{th} percentile as the cutoff point for the comparison group because we wanted the non-dyslexic reading group to represent a large variety of reading competencies but also to omit very weak readers from the non-dyslexic group.

The participants in Study II consisted of four students with dyslexia who also participated in Study I. These four students were selected based on differences in processing patterns observed within the group of students with dyslexia in Study I.
Adolescents (16 year olds) were chosen for this research because multimedia learning and integration between web pages and presentation formats (i.e., representations) are requirements for students at that age level. Also, adolescents are assumed to be able to handle abstract thinking tasks and realize that issues can be understood from multiple perspectives (Blakemore, & Choudhury, 2006).

The inclusion criteria ensured that the participants with dyslexia had been tested within the last two years by the school psychology services, and that participants without dyslexia were not among the 20% poorest readers on national reading tests. Also, none of the participants had ADHD or other comorbid disorders that could have contributed to possible difficulties with multimedia learning. Controlling for comorbidity, although important for validity purposes, was probably one of the reasons we had difficulties recruiting as many participants with dyslexia as we wanted for the empirical research. Participants were recruited by asking the school psychology services if they knew of any 10^{th} graders with dyslexia but without any co-occuring disorders who might be willing to participate. However, many school psychology services did not want to help us recruiting participants because they found it too time consuming, which led to the sampling and testing procedures for the empirical research taking more than 1 year.

3.1.4 Topic used in the empirical studies

To research multimedia learning among adolescent readers, we considered it appropriate to present them with a topic that was both relatively complex and controversial, requiring that students identify different perspectives and integrate them into a coherent understanding. Previous topics used in similar research have concerned possible adverse health effects of consuming artificial sweeteners (Strømsø, Bråten, & Stenseth, 2017) pros and cons regarding the security of nuclear plants (Stenseth, Bråten, & Strømsø, 2016) whether mobile phone radiation can lead to cancer (Strømsø, Bråten, & Stenseth, 2017), and the topic of climate change (Stenseth, Bråten, & Strømsø, 2016). The topic we chose for this research concerned possible harmful and beneficial effects of sun exposure. The topic was considered to have relevance for this age group as Norwegian youths like to sunbathe in order to look tan and healthy (Helland, 2017), which might facilitate engagement with the learning materials. Also, participants could be expected to have at least some background knowledge about this topic, based on the natural science school curriculum.

3.1.5 Materials and measures in the empirical studies

Participants were given access to a researcher generated Internet site titled “Sunbathing and health”. This site contained three different web pages with different views on the issue of sun exposure and health. Each web page contained a title and a lead paragraph explaining the overall content of that page, and then followed a video, a short text, and a picture in that order. The first page contained neutral, factual information about ultraviolet radiation. The second page presented research arguing that sun exposure is healthy because it increases the production of vitamin D. The third page focused on the harmful effects of sun exposure due to increased risk of skin cancer. Thus, the learning materials included two main perspectives on this controversial issue: sun exposure is beneficial versus sun exposure is harmful. The main idea units of the different representations (i.e., the texts, the videos, and the pictures) were unique. This made it possible to trace each idea unit in participants’ post-reading answers to a particular representation on a particular web page.

A standardized test was used to measure participants' word recognition skills (Strømsø, Hagtvet, Lyster, & Rygvold, 1997).

Working memory was measured using a Norwegian adaptation of Swanson and Trahan's (1992) Working Memory Span Task (Braasch et al., 2014). This measure is derived from Daneman and Carpenter's (1980) original Reading Span Test.

To assess participants' knowledge about the topic of sun exposure and health, we administered a 12-item multiple-choice measure. This measure was adapted from a measure used and validated in prior research (e.g., Bråten, Anmarkrud, Brandmo, & Strømsø, 2014), and it was administered both before and after the studying of the three web pages. The items referred to concepts and information relevant to the topic discussed in the learning materials (e.g., UV radiation, skin cancer, and production of vitamin D).

Finally, multiple source integration was assessed by asking participants to respond orally to two open-ended questions after studying the three web pages. These questions were modeled on the integrative short-essay tasks used by Rukavina and Daneman (1996) to measure students' understanding of a controversial scientific issue. Of note is that this approach also has been used effectively in several previous studies of multiple source integration (e.g., Barzilai & Ka'adan, 2017; Bråten et al., 2014; Ferguson & Bråten, 2013).The first question was, "Could you explain the relationship between sun exposure, health, and illness?" The second question was, "Could more than one view on the relationship between sun exposure, health, and illness be correct? Yes or no? If yes, why? If no, why not?" Following Rukavina and Daneman, we considered our first question indirectly to require participants to integrate different perspectives across web pages and representations, or, at least, to consider each perspective's claims and reasons. Our second question was considered directly to require participants to pit perspectives against each other, measuring how well they could reason about the issue in terms of the claims and reasons presented across web pages and representations. See Section 3.1.7 for information about how each student's answers to these two questions were analyzed to yield a total multiple source integration score. For more details about the measures, see Study I and II.

3.1.6 Procedures in the empirical studies

Data were collected on two different days, approximately two weeks apart, in participants' home schools, either during the school day or directly afterwards.

In the first session, the measures of topic knowledge, word recognition, and working memory were administered in that order. The testing lasted approximately 40 minutes. In the second session, participants studied the three web pages with the following instruction read aloud: "Sun exposure and health is a topic of current interest. Imagine that you are supposed to hold an oral presentation on this topic for your fellow students. Here are three web pages you can use to prepare the presentation. You may have 30 minutes studying these pages (please do not take any notes). You can move between the pages as much as you like and read them in the order you choose". The three web pages were presented on a T540P Lenovo laptop with a 15.6" monitor and 1920 x 1080 resolution. All the text material on the three pages was written in black Arial font (size 14) on a white background with 1.5 line spacing. We used a Tobii X2-60 eye tracker to track participants' eye movements while working on the web pages. The Tobii X2-60 is a screen based eye tracker which records gaze data at a sampling rate of 60 Hz. It does not require head rests, and have a high tolerance for movement and various light conditions.

After working on the three web pages, participants completed the topic knowledge test for the second time and responded to the oral integration task. We then replayed the recordings of their eye movements and used these recordings as a cue to interview participants about their processing patterns. The second testing session lasted approximately 60 minutes.

In both testing sessions, all instructions and questionnaire items were read aloud to all participants while they had their own printed copy in front of them. This procedure was followed to ensure that results on the different measures were as little as possible affected by the reading difficulties of the participants with dyslexia. See study I and II for more details about the procedures.

3.1.7 Data analysis in the empirical studies

We used descriptive statistics (means and standard deviations), as well as independent samples *t*-tests and effect size estimates (Cohen's *d*) to compare students with and without dyslexia in Study I. When testing for group differences, we used Holm's (1979) sequential Bonferroni correction to protect against Type 1 error without sacrificing power.

In Study I, we also performed an analysis of covariance (ANCOVA) with group (students with vs. without dyslexia) as the independent variable, multiple source integration as the dependent variable, and working memory and word recognition as covariates. Finally, to examine the role of working memory in the relationship between group membership (students without vs. with dyslexia) and multiple source integration, we tested the indirect effect of group on multiple source integration via working memory. In this analysis, group was contrast coded (without dyslexia = 1, with dyslexia = -1).The other variables were centered and standardized. The indirect effect was tested using a bootstrap estimation approach with 1000 samples (Preacher & Hayes, 2008).

All participants' oral responses to the integration questions were audio taped and transcribed before they were scored. The responses were scored in three steps by a comprehensive procedure explained in detail in the method section of Study I. In the first step, we coded responses to both questions based on the extent to which participants integrated the two main perspectives represented in the materials (i.e., sun exposure is healthy vs. sun exposure is harmful), regardless of the web pages and representations they drew upon in their responses. Participants' scores on the two integrative questions were collapsed. In the second step, we assessed the extent to which participants drew on information from the three different web pages and the different types of representations on each web page (i.e., text, video, and picture) when constructing their oral responses to the two questions. Since the main idea units of each representation were unique, we were able to trace an idea unit included in an oral response back to a particular representation on a particular web page. In the third step, we computed each participant's total multiple source integration score by multiplying the participant's score from the first and second steps. In this way, we considered both the integration of the main perspectives (step one) and the coverage of the learning materials (step two) when assessing multiple source integration (see Study 1 for further details about this scoring procedure).

To check that all participants had read all the material and also to consider differences in processing patterns among the students with dyslexia in Study II, we analyzed eye movement recordings by the means of the Tobii Studio software. In Study II, where we conducted a more detailed analysis of eye movement, we established paragraphs in the texts as the main Areas of Interest (AOI). Within these, we examined the number of fixations, average duration of fixations (measured in milliseconds), and percentage of regressions (i.e., saccadic movements to the left, except for carriage returns). In the reading literature, higher average fixation duration and a high percentage of regressions are considered indicators of comprehension difficulties (Rayner, Chace, Slattery, & Ashby, 2006; Schotter, Tran, & Rayner, 2014).

Specifically, the analysis of participants' eye movements in Study II was carried out in two stages. First, participants' processing patterns on the three web pages where examined with regard to the sequence of processing (i.e., linear vs. non-linear processing pattern) and time spent on the various web pages and representations. Second, we performed more fine grained analyses of eye-movements during the reading of the texts on the three web pages. The first time participants read a paragraph was defined as first pass reading, while any subsequent rereading was considered as second pass reading.

When participants had finished working with the learning material and the post reading measures described in Section 3.1.5, we replayed the recordings of their eye movements and used these recordings as a cue to gain insight into potential deliberate reasons for their processing patterns. This method is called cued retrospective reporting (Van Gog, Paas, Van Merriënboer, & Witte, 2005). We used this method instead of concurrent reporting because concurrent reporting could impact the eye tracking measures, and also because asking struggling readers to think aloud while reading could lead to heavier cognitive load and thus negatively impact the understanding of the learning material. Further cued retrospective reporting is known to lead to better results than plain retrospective reporting, because participants' reports are based on records of their eye movements, which could support their memory and reduce the risk of forgetting and also of fabricating reasoning and thoughts (Van Gog, Paas, Van Merriënboer, & Witte, 2005)

These cued retrospective reports focused on the order in which participants processed the different web pages and representations, and whether the observed processing patterns were representative of how participants typically would approach a web page in an academic setting. Participants' answers were transcribed, and the various utterances were given a time stamp making it possible to connect the utterance to a particular incident in the recordings of the eye movements.

3.1.8 External validity

For a study to have good external validity it should be possible to generalize the findings to the population in question (Shadish, Cook, & Campbell, 2002). This means that the findings from this empirical work would have to be valid for the population of tenth graders with dyslexia in Norway. However, the sample of dyslexic participants we were able to recruit for this research is too small to be representative of this population. This problem can to a certain degree be ameliorated by finding support in other related studies and by making educated assumptions about possible similarities and differences between the participants and the population. Further research obviously is needed in order to draw conclusions regarding the generalizability of the findings obtained in the empirical work included in the present thesis. That said, although it should be acknowledged that further research is needed in order to draw conclusions regarding generalizability, there is no reason to believe that the participants in these studies are atypical. Thus, the findings from this research may have relevance also for other adolescents with dyslexia.

3.1.9 Internal validity

A study has good internal validity if a causal conclusion regarding relations between variables is warranted, which means that a conclusion regarding the effect(s) of an intervention, for instance, can be drawn with a certain degree of confidence (Shadish et al., 2002). Good internal validity normally requires randomization across conditions. Internal validity is less relevant in descriptive studies and studies using correlational data, as was done in the present empirical work. Hence, it is difficult to draw conclusions regarding causality from these studies. However, that being said, it is very likely that the integration problems are caused by dyslexia and not that dyslexia is caused by the integration problems.

3.1.10 Construct validity

Construct validity refers to the degree of coherence between the construct as theoretically defined and the construct as operationalized and measured (Shadish et al., 2002). In educational research, the constructs are often not directly observable, and observable indicators of such unobservable entities are therefore needed, allowing researchers to draw inferences from the observable to the unobservable, as it were (Shadish et al., 2002). For example, inferences may be drawn about constructs such as knowledge and comprehension from verbalizations or other behaviors. In this process, researchers will have to consider which indicators to opt for, and ask themselves to what extent those indicators will capture essential aspects of the theoretical term or construct. Success in this endeavor implies adequate operationalization of the construct, that is construct validity. However, of note is that indicators will never capture a construct in a perfect way and that one never can be entirely sure that "the representation is a proper, true reflection of the object" (Woolgar, 1988). It is also important to note that construct validity concerns the validity of the inferences that can be drawn from the scores on a measure, not the measure itself (Lund, 2002).

In Studies I and II we tried to ensure construct validity by presenting all measures and tasks orally to participants. In this way, we tried to avoid testing participants' reading and writing skills in addition to their topic knowledge and multiple source integration. This seems especially important since half of the participants were diagnosed with dyslexia. In Study II, in particular, we combined the objective measure of eye tracking with qualitative interview data cued by eye movement recordings to gain better insight into participants' information processing. Because eye tracking results are not self-explanatory, eye tracking used in combination with other measures may be needed to draw valid inferences about processing from such data (Kok & Jarodzka, 2017).

3.1.11 Reliability

Reliability is about the amount of measurement errors in the scores of tests, in other words the precision with which tests measure what they are supposed to measure (Kleven, 2002a). Reliability can thus be considered a prerequisite for construct validity (Kleven, 2002a).

All measures used in this thesis have shown adequate reliability in previous empirical work, although the reliability of the topic knowledge measure (.69 at pre-test and .71 at post-test) was somewhat lower than desirable in the present research. Further, to ensure interrater reliability for the multiple source integration scores, two independent raters scored a random selection of 50% of participants' oral responses, initially agreeing on 80-85% and resolving all disagreements through discussions.

3.1.12 Ethical considerations

The collection and handling of all data in the thesis project met the requirements of the Personal Data Registers Act and was based on the guidelines from the Norwegian Social Science Data Service (NESH, 2006). Amongst these requirements are the need to ensure freedom and self-determination, safeguard against harm and unreasonable suffering, protect privacy and close relationships, and the obligation to obtain free and informed consent (NESH, 2006). This study was also conducted in accordance with the guidelines from the National Committee for Research Ethics in the Social Sciences and Humanities (NESH, 2006), and it was approved by the Norwegian Centre for Research Data.

With regard to the obligation to obtain free and informed consent, all participants in this research were adolescents about 15-16 years of age. Young people are entitled to special protection when they participate in research. Parental consent is usually required when children under the age of 15 are participating in research, but since we included participants diagnosed with dyslexia, we ensured parental consent although all participants were above the age of 15. Also, the information about participation in the study was given orally as well as in writing to ensure fully informed consent. Last but not least important, confidentiality was ensured by keeping the matching key between names and responses locked away separately and by giving no one but the researcher access to this key.

3.2 Methodological approach in study III

The third study is a systematic review of research studies published between 2014 and 2017 on multimedia learning that uses cognitive load theory as the major theoretical framework, with a particular focus on how working memory has been conceptualized in these studies and how subjective measures of cognitive load have been used. Systematic reviews use systematic methods to collect secondary data, critically appraise research studies, and synthesize studies that are relevant to answer clearly formulated research questions (Moher, Liberati, Tetzlaff, & Altman, 2015). Further, systematic reviews are used to describe trends in the research field by, for instance, investigating how many studies have used certain research methodologies. We did not use statistical techniques to analyze the results from the studies included in the systematic review. The study therefore is not a meta-analysis (Moher et al., 2015).

The review included 73 studies of multimedia learning which met the following inclusion criteria: they cited and built upon cognitive load theory as a major theoretical framework, used a subjective measure of cognitive load, either as the only measure or in combination with other measures, addressed learning in a formal educational context using a multimedia tool, and, finally, included participants without any identified cognitive impairment or learning disability. The search for studies was conducted in October 2017 and included four databases that represented both educational and psychological domains: ERIC, Social Sciences Citation Indexes, PsycINFO, and Web of Science. Search terms for cognitive load included cognitive load, mental load, workload and mental effort. These search terms were combined with "multimedia" and/or "multimedia learning". We also developed a coding scheme to extract the following information from the selected studies: 1) study aim, including main research question(s); 2) method, including description of participants (age, educational background, and sample size), study design, multimedia tasks, measure(s) of cognitive load, procedures for measuring cognitive load, and measure of working memory (if measured); 3) conceptualization of working memory in the study's literature review, including definition of working memory and references for this definition; 4) findings regarding the relationship between cognitive load and learning, categorized as negative (i.e., high cognitive load was associated with low learning), positive, or neutral; and 5) findings regarding the relationship between cognitive load and working-memory capacity, categorized as negative (i.e., high working memory capacity was associated with low cognitive load), positive, or neutral.

The reason we restricted our search to the time period of 2014-2017 is that there has recently been discussions in the literature about whether subjective measures are sufficiently sensitive to capture cognitive load (e.g., Ayres, 2006; Brünken et al., 2003). Also, lately there has been much criticism of cognitive load theory with regard to measurement issues (e.g., de Jong, 2010; Naismith et al., 2015). We therefore wanted to determine whether the most recent published research on multimedia learning using subjective measures of cognitive load had responded to this critique by using scales with greater specificity and/or more items, and by evaluating how cognitive load measured by means of subjective rating was related to learning.

3.3 Methodological limitations

There are some noteworthy limitations in the methodology of the two empirical studies included in this thesis. First, with regard to participants, there is a possibility that adolescents, despite the expected relevance of the topic (i.e., sunbathing and health), could be less likely than adults to put time and effort into the experimental learning task (Bråten, Brante, & Strømsø, in press). On the other hand, participants at this educational level are required to learn from multimedia materials at school and can be considered to manage the complexity of the task (Blakemore & Choudhury, 2006). Also, the materials and measures were administered individually, which could increase the likelihood of engagement with the tasks.

With regard to validity, the mock Internet site including only three web pages could be considered a threat to the ecological validity of the research. On the other hand, the use of a closed site was warranted by the need to trace post reading oral responses back to specific web pages and representations. Also, we wanted to enhance construct validity by ensuring that we measured the complexity of the integration task per se and not the influence of commercials and the many other distractors that typically appear on authentic web pages. Further, the topic of sun exposure and health was chosen by the researcher in advance, which might have influenced the findings due to factors such as the topic interest and prior knowledge of the participants.

As noted above, the small sample size is a limitation with respect to the external validity of the research. Also, the students with dyslexia who volunteered to participate may have represented a certain type of students with dyslexia (e.g., the ones interested in participating in research), causing a form of self-selection bias (Kleven, 2002b). However, that being said, the students with dyslexia were recruited from 10 different schools in five different counties in Norway, showing large heterogeneity both on school and participant level. Finally, participants were rewarded a gift card and the opportunity to get instruction in reading strategies that could be useful for their school work. This might imply that we attracted participants who mainly wanted such “rewards” rather than participants being interested in the learning tasks.

With regard to the mixed methods design used in study II, there are some pitfalls and challenges in using a combination of qualitative and quantitative methods. The use of qualitative measures in combination with quantitative measures places some constraints on the measures as they have to be compatible, i.e. they must examine the same phenomenon without negatively affecting the quality of the data. There are two reasons why Study II used qualitative data from retrospective cued reports instead of think aloud protocols, which are often used in research on trouble solving and reading (Anmarkrud et al, 2014; Van Gog, Paas, & Van Merriënboer, 2005). First, since multimedia learning is supposed to be cognitively challenging and students with dyslexia could be expected to experience even more cognitive load than typically developed readers, think aloud protocols were not considered suitable, as they can have a negative impact on task performance (Schooler, 2011). This could then lead to a problem with construct validity. Second, thinking aloud during processing may interfere with the eye movements (Van Gog, T., & Jarodzka, H. 2013), and it could therefore lead to less valuable eye tracking measurements. This issue could be seen as an example of the challenge of integrating qualitative and quantitative methods. One has to ensure that the two methods actually supplement each other and do not sit in parallel, or, even worse, that the combination of two methods leads to a problem with construct validity.

Of note is that the retrospective reports used in Study II were interview data cued by the recordings of participants' eye movements replayed to the participants after the assessments. The interview questions thus depended on what the recordings showed but were not formulated in advance (for instance: "I see that you start reading the text on this web page instead of watching the video at the top of the page. Could you explain why?"). In this way, the interview was structured in the sense that it was framed by what went on in the recordings, and it would not have been relevant to talk about something entirely different.

4 Summaries of papers

Paper I: Investigating Multiple Source Use among Students With and Without Dyslexia

The aim of paper I was to compare dyslexic and non-dyslexic students' learning and integration when reading multiple sources on a socio-scientific issue in a digital environment. The study in this paper was guided by the following research questions:

1a) To what extent do students with and without dyslexia differ with respect to learning from and integrating information across different web pages and representations when working with conflicting information about a controversial socio-scientific issue?

1b) Can likely differences in integration of information across web pages and representations between the two groups of students be explained in terms of differences between the two groups with respect to word recognition, working memory, or both?

There is a lack of research on students with dyslexia and multimedia learning. Although reading on the Internet has been assumed by many to be more accessible to students with dyslexia than reading on paper, because of the support from pictures, audio files, and videos, this kind of learning draws heavily on reading proficiency and working memory and could therefore be more challenging for students with dyslexia than for typically developing readers. Participants were 44 tenth-graders, of these 22 had been diagnosed with dyslexia. Participants read a mock Internet site containing three different web pages, each page including a video, a text, and a picture, about the controversial issue of sun exposure and health. Prior knowledge, word recognition and working memory were measured. Participants also answered knowledge and integration questions after working on the three pages. Results showed that there were no reliable differences between the two groups with regard to pre-reading topic knowledge, post-reading topic knowledge, or knowledge gain. In contrast, participants without dyslexia clearly outperformed participants with dyslexia on a multiple source integration task and drew to a much larger extent on textual sources when constructing their oral responses. Results also indicated that working memory differences between the two groups were the main contributor to observed differences with respect to multiple source integration. This failure to include text in the integration of information from different pages may seriously hamper dyslexic students' ability to construct integrated understandings of information on socio-scientific issues presented online. This is because text is common on such pages, and because readers do not necessarily get all information they need from other presentation formats (e.g. pictures and videos).

Paper II: Processing and Learning from Multiple Sources: A Comparative Case Study of Students with Dyslexia Working in a Multiple Source Multimedia Context

Building on the findings of paper I, paper II focused on variations in processing patterns among four of the 10th graders with dyslexia who had also participated in the study reported in paper I. The four participants were selected based on differences among the students with dyslexia. We specifically wanted to examine if differences in participants' processing patterns were related to cognitive differences and to performance on post-reading learning and integration tasks, and the study described in this paper addresses the following research questions:

2a) To what extent are there variations in processing patterns among students with dyslexia when reading multimodal information on different web pages and to what extent do these processing patterns represent deliberate, strategic activity?

2b) How are processing patterns related to individual differences among participants and to their learning from and integration of multimodal information presented on different web pages?

An eye-tracker was used to record the processing patterns of participants while working on three multimedia web pages containing conflicting information. In addition, word recognition, working memory, knowledge about the topic, and integrated comprehension were assessed. The study indicated that students with dyslexia may, indeed, display different processing patterns when dealing with multimedia. However, while the participants may have processed web pages strategically to improve their conceptual learning, they seemed to have problems memorizing details and integrating information at the same time. Thus, the participants who displayed relatively large knowledge gains, did not integrate information well, and the participant who did not gain much in regard to knowledge, did relatively well on the integration task. The findings suggested that the high processing demands of word reading, typical for struggling readers, and the processing demands represented by the need to integrate information across different pages and representations, could lead to cognitive overload for these readers, and that differences in processing could be related to cognitive differences and performance on post-reading learning and integration tasks.

Paper III: Cognitive Load and Working Memory in Multimedia Learning: Conceptual and Measurement Issues

In the last decade, cognitive load theory has been the subject of strong criticism regarding methodological and measurement issues (De Jong, 2010; Gerjets, Scheiter, & Cierniak, 2009) and conceptual clarity (De Jong, 2010; Schnotz & Kürschner, 2007). Hence, we wanted to examine whether this critique had resulted in more rigorous measurements and more conceptual clarity in the most recent research on cognitive load in a multimedia context. Paper III therefore reviewed contemporary research (2014-2017) on multimedia learning using cognitive load theory as the major theoretical framework to answer the following research questions:

3a) How is working memory conceptualized in contemporary cognitive load research on multimedia learning, and to what degree is working memory assessed in this research?

3b) How are subjective measures of cognitive load used in this research, and are subjective measures combined with other measures of cognitive load?

3c) How are the results from subjective measures of cognitive load related to learning and achievement?

The findings showed that most of the reviewed studies did not include any conceptualization or clear definition of working memory, used only general subjective measures containing one or very few items, and did not report findings consistent with the hypothesized relationship between cognitive load and multimedia learning.

Table 1. Overview of studies

	Study I	Study II	Study III
Title	Investigating Multiple Source Use among Students with and without Dyslexia	Processing and Learning from Multiple Sources: A Comparative Case Study of Students with Dyslexia Working in a Multiple Source Multimedia Context	Cognitive Load and Working Memory in Multimedia Learning: Conceptual and Measurement Issues
Purpose	To compare dyslexic and non-dyslexic students' learning and integration of information across web pages and representations (i.e., texts, pictures, and videos) when working with multiple conflicting sources on a socio-scientific issue in a digital environment.	To examine processing patterns, learning and integration of four students with dyslexia working in a multiple source multimedia environment.	To review contemporary research on multimedia learning that uses cognitive load theory as the major theoretical framework
Research questions	1. To what extent do students with and without dyslexia differ with respect to learning from and integrating information across different web pages and representations when working with conflicting information about a controversial socio-scientific issue? 2. Can likely differences in integration of information across web pages and representations between the two groups of students be explained in terms of differences between the two groups with respect to word recognition, working memory, or both?	1. To what extent are there variations in processing patterns among students with dyslexia when reading multimodal information on different web pages and to what extent do these processing patterns represent deliberate, strategic activity? 2.How are processing patterns related to individual differences among participants and to their learning from and integration of multimodal information presented on different web pages?	1. How is working memory conceptualized in contemporary cognitive-load research on multimedia learning, and to what degree is working memory assessed in this research? 2. How are subjective measures of cognitive load used in this research, and are subjective measures combined with other measures of cognitive load? 3. How are the results from subjective measures of cognitive load related to learning and achievement?
Design	Quantitative comparative study	Mixed methods multiple case study	Systematic review
Part./No of studies	44 tenth-graders (15-16 years old), 22 with and 22 without dyslexia	4 tenth graders (15-16 years old)	73 studies included
Data	Eye tracking recordings, topic knowledge, multiple source integration, word decoding and working memory measures.	Eye tracking recordings, post reading interviews, topic knowledge, integration questions and working memory measures.	73 studies about subjective rating of cognitive load in multimedia learning.
Main findings	No reliable differences between the two groups with regard to pre-reading topic knowledge, post-reading topic knowledge, or knowledge gain. Participants without dyslexia clearly outperformed participants with dyslexia on the multiple source integration task (d = 1.16) and were much more likely to draw on textual sources when constructing their oral responses (d = 1.26). Finally, there were no reliable differences between the two groups with regard to use of pictorial or video sources.	All participants gained knowledge about the topic. All participants read the texts and also drew on textual information on the post-reading knowledge task. On the integration task, none of the participants drew on textual information presented on the websites.	The findings showed that most of the reviewed studies did not include any conceptualization or clear definition of working memory, used only general subjective measures containing one or very few items, and did not report findings consistent with the hypothesized relationship between cognitive load and multimedia learning

5 Discussion, suggestions for further research, and educational and theoretical implications

5.1 Discussion of main findings

The aim of this thesis was twofold. First, to investigate possible differences between typical and struggling readers as well as between struggling readers when learning about a social-scientific issue in a multiple source multimedia context. This was addressed in the first two studies included in the thesis. Second, to review contemporary research on multimedia learning that uses cognitive load theory as the major theoretical framework, especially how working memory has been conceptualized in this research, how subjective measures of cognitive load have been used, and how results from such subjective measures have been related to learning and achievement. This was addressed in the third study included in the thesis.

In the study comparing students with and without dyslexia, it was found that both groups of students were able to improve their scores on the topic knowledge test, but that students with dyslexia experienced greater difficulty with the integration task than did students without dyslexia. Specifically, students with dyslexia were much less likely to draw on textual sources in the integration task. Such challenges related to integration could be due to poor word recognition skills, implying that word reading may draw so heavily on working memory resources that insufficient resources are available for the integration of information. Another possible explanation is that limited working memory capacity among students with dyslexia is the main contributor to poor multiple source integration. Yet another possibility is that both poor word recognition skills and limited working memory capacity play important roles. When we investigated this issue, the results of our analysis of covariance showed that after adjusting for differences between the two groups of students with respect to word recognition skills and working memory capacity, no statistically significant difference between the two groups was observed on the multiple source integration task. Moreover, in this analysis, only working memory capacity had a statistically significant effect on multiple source integration, which indicates that the difference between students with and without dyslexia on this task to a large extent could be attributed to the difference in working memory capacity between the two groups. This finding is supported by research findings regarding working memory in students with dyslexia and working memory and multimedia learning previously discussed (see Sections 2.3.1 and 2.2.4).

In studying differences between students with dyslexia, as was done in Study II, processing patterns were investigated in relation to cognitive differences and performance on post-reading learning and integration tasks. The findings showed that in addition to differences in reading skills, the participants with dyslexia displayed different processing patterns in the multiple source multimedia context, and these factors together predicted outcomes on topic knowledge and integration tasks. One possibility is that the differences in processing patterns that were observed were due to differences in reading speed. Thus, whether participants first tried to get an overview of the three pages and then read the texts in depth, or whether they studied the pages one or more times, could depend on their reading speed. All participants read all texts at least once, but the best performing participant systematically overviewed the entire web environment by looking at all web pages before starting to read one of the texts, and additionally read the headline of each web page before studying one of the representations. This presumably led to a better understanding of the content of the three web pages than just studying all three web pages once. Also, readers with better word recognition and, consequentially, higher reading speed will presumably have more cognitive capacity left for understanding the content, and for switching between pages and representations without forgetting what they read, whereas readers with poorer word recognition are more likely to spend cognitive capacity on the decoding part of reading, which could lead to less capacity left for understanding the content. This is in line with the finding that the student with the lowest word recognition score also scored lowest on the integration task, and with research previously cited in this thesis stating that multimedia learning can be challenging for students with dyslexia (see Section 2.3.2).

The findings of the second study, contrary to our expectations, also showed that none of the students used a picture-to-text approach, but that two of the participants started reading the text before watching the videos and pictures, which is in accordance with a text-to-picture processing approach (Hegarty & Just, 1993). This prioritization of text can also be due to the text superiority effect (e.g., Corriveau, Einav, Robinson, & Harris, 2014; Einav, Robinson, & Fox, 2012; Eyden, Robinson, Einav, & Jaswal, 2013), which posits that students tend to trust and emphasize textual information more than other types of information, in particular in an academic context such as the one created in this study.

Moreover, the students with dyslexia participating in the second study seemed to have problems memorizing details and integrating information at the same time. This could possibly be explained by the non-linearity of the learning environment, which seems to require high level reading skills and reflection, as well as more complex applications of knowledge (Chan & Unsworth, 2011; Coiro & Dobler, 2007). Another finding of the second study was that none of the participants drew on textual information in the integration task, although all participants read all texts. One possible explanation is that the participants, due to their reading problems, constructed a rather fragile mental model of the text content which was not coherent enough to serve as the basis for a complex integration task. As stated earlier, readers struggling with the decoding part of reading likely will have less capacity left to understand and remember what they have read, which could contribute to difficulties with the complex integration task. In other words participants with dyslexia can experience cognitive overload in a multiple source multimedia learning environment.

Study three examined a sample of studies conducted between 2014 and 2017 of multimedia learning framed by cognitive load theory that measured cognitive load by means of subjective ratings. The purpose was to investigate whether this area of research had responded to recent criticism regarding methodological issues and conceptual clarity by using scales with greater specificity and/or more items, and to evaluate how measurements of cognitive load were related to learning. This examination found that the Paas (1992) scale was most frequently used to measure cognitive load, but often in adapted and modified versions without a consideration of the possible impact of these modifications on the psychometric properties of the instrument. This makes it difficult to interpret the findings of these studies. It is also a reason for concern that data on the psychometric properties of subjective measures of cognitive load are still lacking in many studies. Further, our review showed that although researchers posit that they build on working memory theory, they seldom refer to it. That is, most of the reviewed studies did not include any conceptualization or clear definition of working memory. This is surprising as cognitive load theory is based on the idea that instructions should be designed to take humans' limited working memory capacity into consideration. Thus, although the relation between cognitive load theory and the concept of working memory is not straight forward, working memory could be seen as one of the cornerstones of cognitive load theory. It could therefore be expected that research using cognitive load theory as the major theoretical framework should provide clear conceptualizations of working memory. Also, as recommended by de Jong (2010), working memory should be included in studies of cognitive load to increase validity, as this will ensure that differences between groups cannot be attributed to differences in working memory.

The review also showed that most of the studies used only general subjective measures containing one or very few items. Although the Paas (1992) measure has been assumed to be reliable in measuring subjective perceptions of invested effort, it is still unclear how this mental effort relates to actual cognitive load. To increase validity, it could therefore be argued that subjective measures would have to be combined with other, preferably objective measures of cognitive load (Inan et al., 2015). However, among the studies that were reviewed as part of this thesis, only 10 studies used multiple measurements of cognitive load, typically combining subjective ratings with a secondary task.

5.2 Suggestions for future research

Further research is required to probe the generalizability of our findings, since this study included a limited number of students who volunteered to participate. Second, because the results were based on correlational data that do not warrant conclusions regarding causality, experimental approaches are needed in future research to draw firmer conclusions regarding causal relationships. Moreover, future research should investigate other topics than sun exposure and health, as the topic of the materials may influence results due to factors such as topic interest and prior knowledge. Because the mock internet site with only three web pages could be considered a threat to the ecological validity of the tasks, further research is also needed where students with and without dyslexia are compared when learning with and from more authentic online materials. Finally, future research should take gender differences into account. There was an overrepresentation of males among the dyslexic participants in the current research that might have affected the findings. To a certain extent, this overrepresentation reflected the gender ratio within the group of students diagnosed with dyslexia in the population, which is reported to range between 1.2:1 and 3.3:1 (Rutter et al., 2004; Shaywitz, Shaywitz, Fletcher, & Escobar, 1990). Of course, the overrepresentation of male students with dyslexia in the current study reflected the gender ratio among those who volunteered to participate in the research.

5.3 Educational implications

Despite the limitations, the studies included in this thesis may represent a timely integration of the study of dyslexia and the study of learning in multimedia environments, which may also have some practical implications. Thus, the findings indicated that students, in particular, students with dyslexia, may need assistance in dealing with multimedia learning environments. This is in line with Goldman, Snow, and Vaughn (2016), who argued that even typically developing readers need help in order to master the increasingly complex reading environments characterizing the digital age. They suggested that literacy projects for all students may be effective when students are engaged in active, purposeful reading, when they receive social support from teachers and peers, and when instruction leverages prior knowledge and introduces key concepts and vocabulary. This is in accordance with research findings indicating that teachers need training and resources to be able to integrate the Internet into instruction (Sanchez, Marcos, Gonzales, & GuanLin, 2012; Smarkola, 2008). In other words, although students have reached an age where they are supposed to be reading to learn instead of learning to read (Goldman, Snow, & Vaughn, 2016), the complex multimedia environments of new literacy seem to require extra support for students to benefit from their affordances.

Thus, although it has been argued that reading on the Internet is beneficial for students with dyslexia due to visual support from pictures and videos (Scheiter & Gerjets, 2007), multimedia learning environments seem to place additional demands on struggling readers. In fact, there is a lack of support for the widespread belief that the challenges students with dyslexia face in a multimedia academic setting, to a large degree can be ameliorated by assistive technology such as apps and pc tools especially designed to help dyslexics. Teachers therefore need to learn more about how students with dyslexia can be supported when learning in multimedia environments.

Latini, Anmarkrud and Brandmo (2018), in a recent study of teachers' self-efficacy for instructing dyslexic students in Internet reading, found that experience with teaching Internet reading and beliefs and knowledge about dyslexia and dyslexic students' abilities predicted this form of teacher efficacy. However, recent research has revealed gaps in teachers' knowledge about dyslexia (Olofsson, Ahl, & Taube, 2012; Soriano-Ferrer, Echegaray-Bengoa, & Joshi, 2016; Washburn, Binks, & Joshi, 2014). This suggests that more focus on dyslexia is needed in the teacher education curriculum, and that use of the Internet for academic purposes needs to be addressed in both teacher education and special needs education. In particular, as a core skill in multimedia learning contexts, integration should be taught systematically across genres and disciplines and not only within specific writing genres (Barzilai, Zohar, & Mor-Hagani, 2018).

5.4 Theoretical implications

This research brings together two fields that have traditionally been kept separate in research and theory, that is, the study of dyslexia and the study of learning in multimedia environments. One theoretical contribution of this thesis is the finding that the multimedia principle, stating that people learn more from pictures and text than from text alone, may not be applicable to dyslexic students. In particular, the suggestion that the combination of multiple sources and representations (text, videos, pictures) and the need to integrate information across these sources and representations, can lead to cognitive overload for readers with dyslexia. Also, the findings suggest that students with dyslexia may have particular problems with using information from text in complex integration tasks, corroborating prior research (Beacham & Alty, 2006).

Finally, the review study included in this thesis contributes theoretically by highlighting the need for more sensitive and specific measures of cognitive load. In particular, such measures are needed to increase the precision of results concerning the effects of new instructional designs. For example, the combination of subjective measures with other kinds of measures, such as physiological measures, could lead to enhanced construct validity and more consistent findings. This is important in order to construct multimedia learning environments in the best possible way for all learners.

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Dissertational Papers

I

II

III

Appendices

I

II

Appendix I:

Approval from the Norwegian Centre for Research Data and information

I

Norsk samfunnsvitenskapelig datatjeneste AS
NORWEGIAN SOCIAL SCIENCE DATA SERVICES

Harald Hårfagres gate 29
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0318 OSLO

Vår dato: 17.11.2014 Vår ref: 40644 / 3 / JSL Deres dato: Deres ref:

TILBAKEMELDING PÅ MELDING OM BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 07.11.2014. Meldingen gjelder prosjektet:

40644	*Digital natives with reading difficulties: A study of dyslectic adolescents integration of conflicting information across Internet sites and presentation formats*
Behandlingsansvarlig	*Universitetet i Oslo, ved institusjonens øverste leder*
Daglig ansvarlig	*Anette Andresen*

Personvernombudet har vurdert prosjektet, og finner at behandlingen av personopplysninger vil være regulert av § 7-27 i personopplysningsforskriften. Personvernombudet tilrår at prosjektet gjennomføres.

Personvernombudets tilråding forutsetter at prosjektet gjennomføres i tråd med opplysningene gitt i meldeskjemaet, korrespondanse med ombudet, ombudets kommentarer samt personopplysningsloven og helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema, http://www.nsd.uib.no/personvern/meldeplikt/skjema.html. Det skal også gis melding etter tre år dersom prosjektet fortsatt pågår. Meldinger skal skje skriftlig til ombudet.

Personvernombudet har lagt ut opplysninger om prosjektet i en offentlig database, http://pvo.nsd.no/prosjekt.

Personvernombudet vil ved prosjektets avslutning, 01.02.2018, rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Katrine Utaaker Segadal

Juni Skjold Lexau

Kontaktperson: Juni Skjold Lexau tlf: 55 58 36 01
Vedlegg: Prosjektvurdering

Dokumentet er elektronisk produsert og godkjent ved NSDs rutiner for elektronisk godkjenning.

Personvernombudet for forskning

Prosjektvurdering - Kommentar

Prosjektnr: 40644

Det er uklart om det behandles personidentifiserende opplysninger i prosjektet. Men så vidt vi forstår skal det foreligge en kobling til navneliste e.l. Vi behandler derfor prosjektet som meldepliktig etter personopplysningsloven.

Utvalget (ungdommer og foreldre) informeres skriftlig om prosjektet og samtykker til deltakelse. Informasjonsskrivet er godt utformet. Vi forutsetter at ungdommene også får muntlig informasjon, siden halvparten av dem har dysleksi.

Samtykkeerklæringen må endres slik at det er tydelig at ungdommen/foreldrene gir tillatelse til at forsker får tilgang til rapporter om barnet fra PPT. Dette kan eksempelvis gjøres ved at det er ulike avkryssingspunkter: a) jeg samtykker til å gjennomføre testene/oppgavene og b) jeg samtykker til at forsker får tilgang til rapporter om meg/mitt barn fra PPT. Dette er nødvendig for å sikre at det foreligger et reelt informert samtykke til opphevelse av taushetsplikten hos PPT.

Hvis undersøkelsene gjennomføres i skoletiden, skal det legges opp til at elever som ikke ønsker å delta får tilbud om et alternativt undervisningsopplegg.

Det behandles sensitive personopplysninger om helseforhold.

Personvernombudet legger til grunn at forsker etterfølger Universitetet i Oslo sine interne rutiner for datasikkerhet.

Forventet prosjektslutt er 01.02.2018. Ifølge prosjektmeldingen skal innsamlede opplysninger da anonymiseres. Anonymisering innebærer å bearbeide datamaterialet slik at ingen enkeltpersoner kan gjenkjennes. Det gjøres ved å:
- slette direkte personopplysninger (som navn/koblingsnøkkel)
- slette/omskrive indirekte personopplysninger (identifiserende sammenstilling av bakgrunnsopplysninger som f.eks. bosted/arbeidssted, alder og kjønn)
- slette videoopptak

Forespørsel om deltakelse i forskningsprosjektet

"Undersøkelse om arbeid på internett hos ungdom med dysleksi"

Bakgrunn og formål
Vi henvender oss til dere i forbindelse med et forskningsprosjekt ved Institutt for spesialpedagogikk ved Universitetet i Oslo, hvor vi vil undersøke hvordan ungdom med dysleksi jobber med internett-tekster. Vi ønsker å få et bilde av hva de gjør mens de surfer på internett. Dette skal brukes til å veilede elever med dysleksi i hvordan de kan arbeide mest mulig effektivt med slike oppgaver.

Vi ønsker å komme i kontakt med 9. og 10.-klassinger som har dysleksi, og det er i den forbindelse dere har fått dette brevet.

Hva innebærer deltakelse i studien?
I tillegg til å surfe på noen internettsider som handler om naturfag, vil deltakerne svare muntlig på noen spørsmål om hva de synes om de ulike nettsidene, hva som eventuelt var vanskelig, og hva de husker av det de har lest.

Deltakerne vil også besvare noen spørsmål muntlig før og etter arbeidet med nettsidene, og vi ønsker å få tilgang til rapporter fra PPT med resultater fra dysleksiutredningen.

Data registreres i form av svar på spørsmål, notater og lydopptak av noen av elevsvarene. I tillegg vil vi registrere øyebevegelsene på skjermen, for å se hva de retter oppmerksomheten mot.

Undersøkelsene fordeles over to økter, hver på mellom 45 og 60 minutter. Vi håper deres barn ønsker å delta. *Undersøkelsen vil foregå på elevens skole.* Deltakerne vil bli belønnet med et gavekort på kr. 300,-.

Hva skjer med informasjonen om deg?
Alle personopplysninger vil bli behandlet konfidensielt, og det vil ikke være mulig å identifisere hvem som har svart hva i oppgavene. Eventuelle navnelister/koblingsnøkler vil lagres adskilt fra øvrige data. Deltakerne vil ikke kunne gjenkjennes i publikasjoner.

Prosjektet skal etter planen avsluttes 1. februar 2018. Datamaterialet blir anonymisert ved prosjektslutt.

Frivillig deltakelse
Det er frivillig å delta og mulig å trekke seg når som helst i løpet av prosjektet, uten at man trenger å begrunne dette. Dersom barnet ditt trekker seg, vil alle opplysninger om ham/henne bli slettet. Doktorgradsstudent, forskningsassistenter og veileder er underlagt taushetsplikt.

Dersom du har spørsmål til studien, ta kontakt med doktorgradsstipendiat Anette Andresen (doktorgradsstipendiat) på mail: anette.andresen@isp.uio.no eller tlf. 22854007.

Studien er meldt til Personvernombudet for forskning, Norsk samfunnsvitenskapelig datatjeneste AS.

Dersom dere ønsker å delta i denne undersøkelsen ber vi dere sende en mail til anette.andresen@isp.uio.no for å bekrefte deltagelsen. Selve svarslippen (se neste side) kan vi få i forbindelse med datainnsamlingen.

Samtykke til deltakelse i studien

Jeg har mottatt informasjon om studien, og samtykker i at mitt barn kan delta ☐

Jeg samtykker til at forsker får tilgang til testresultater og sakkyndig uttalelse fra PPTs dysleksiutredning av mitt barn ☐

(Signert av foresatt, dato)

Jeg har mottatt informasjon om studien, og er villig til å delta

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(Signert av elev, dato)

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Vi ønsker også å komme i kontakt med 10.-klassinger som IKKE har dysleksi, og som skal være kontrollgruppe, og det er i den forbindelse dere har fått forespørselen.

Hva innebærer deltakelse i studien?
I tillegg til å surfe på noen internettsider som handler om naturfag, vil deltakerne svare muntlig på noen spørsmål om hva de synes om de ulike nettsidene, hva som eventuelt var vanskelig, og hva de husker av det de har lest. Deltakerne vil også besvare noen spørsmål muntlig og skriftlig før og etter arbeidet med nettsidene.

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Dersom du har spørsmål til studien, ta kontakt med professor Øistein Anmarkrud (veileder) på mail: oistein.anmarkrud@isp.uio.no eller tlf. 22858046 eller doktorgradsstipendiat Anette Andresen (doktorgradsstipendiat) på mail: anette.andresen@isp.uio.no eller tlf. 22854007.

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(Signert av foresatt, dato)

Jeg har mottatt informasjon om studien, og er villig til å delta

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(Signert av elev, dato)

Appendix II:

Measures

II

Ordkjeder

Hver ordkjede består av tre vanlige ord. Du skal markere de tre ordene ved å sette to streker, f.eks.: avrommøte

Under følger 3 ordkjeder som du kan trene på :

etterkartmøte svarserrot hoppturmat

Dersom du står fast på en ordkjede, kan det lønne seg å gå videre til neste ordkjede.

(Løsning på treningsoppgavene : etter/kart/møte svar/ser/rot hopp/tur/mat)

Ikke bla om før du får beskjed !!

ORDKJEDER

morheihus	seogtur	solvedår	gatefarbra	4
dagpilår	helbrevrøk	snøbåtku	radmusbad	8
syfathet	brunhulfet	servinby	vårspydrom	12
matfotnål	øremånetur	ropfredvet	planbenhøre	16
romknivben	apeblåbank	gatefrubok	kaffepelsgul	20
lusklubbond	oppkattløs	ålfluetelt	folkhestfri	24
urkakepose	ondmygghull	grynliteslit	armflaskebly	28
gulgrynute	grisløpehest	tåmyrdefull	ryggdoktormur	32
vannbokaopp	langmånerive	smørhavfilm	stoppsovegul	36
papirvitenpil	dameflaggby	stuegransaks	liggegråsmil	40
årtomjente	matsyklerkar	ølbuskoffer	brevsmørse	44
åpnekappesekk	ettdoktorfull	melkstyreløpe	markreddblir	48
mopedgravfin	partifredhår	revgaleolje	grøtgradingen	52
hoppbråkland	noenjulseks	underårhoste	svømmekremknagg	56

bospøkevind	dagnavnglass	slåbakrolig	mannbladsving	60
liteøverstbo	skapgladpinne	knivtomtrop	håphithest	64
ålmellomfram	prøvesmalfem	aldriryggeller	sistdatomotor	68
soldatsugeelv	trådfilmstol	slåtenkehet	pianofåmur	72
ringetivin	rekkefyrførst	språkpakkemyr	gladsistvask	76
elvpratring	slagtåkamp	dommerkroskrot	støpegranvask	80
medlemølgate	smalsysaft	krisedødelek	knebankpenner	84
vakkerryggskap	gaffelfiskskolen	statlefineste	stilmyktvekt	88
femaldrirøk	utmøbelkniv	stopphumørdø	vanngrusprøve	92
strengstellgrå	stekhjelpfat	snuvinktrinn	tåspeilsone	96
vesentristfalsk	lastlivalle	jaktnæretre	fiendefriførst	100
tolvfjærspurv	brordårligbolle	elskeuglefram	ivrigsvinpave	104
busspostennød	tidaktivrød	snarttrordikt	kritiskellertann	108
sidehavsamle	fengselnebbgul	kranvarhare	tallmersist	112
hallklemmotor	saktebadbensin	kildetravelgro	spenttvilklo	116
driveærligandre	effekttapemin	ansiktbilletthull	herslutterdet	120

Oppgaver til Arbeidsminneprøven

Instruksjon (etter først å ha delt ut utfyllingsarket til elevene): ”Nå skal jeg lese opp noen setninger, og så skal du få et spørsmål om innholdet i en av setningene. Du må konsentrere deg godt, for etterpå skal du gjøre to ting: Du skal svare på spørsmålet, og du skal prøve å huske det siste ordet i hver setning. Du skal skrive svarene på arket, som ser ut slik som jeg har tegnet det på tavla.

Men først skal vi ta et par eksempler. La arket ligge så lenge. Vi skal ikke skrive noe ennå.”

Eksempel 1: Følgende serie på to setninger med spørsmål leses opp for elevene:

En katt har ni liv.

Mona spiser mange knekkebrød til frokost.

Spørsmål: Hva slags mat spiser Mona til frokost? (Svar: knekkebrød). *Husker du det siste ordet i hver av de to setningene?* (liv – frokost).

Prøveleder viser på tavla hvordan de åpne feltene skal fylles ut.

Eksempel 2: Her er en serie med 3 setninger samt spørsmål:

Etter trening drar Kari på kino.

Blomstene er store og gule.

Petter henter bilen.

Spørsmål: Hva gjør Kari før hun går på kino? (Svar: trener/ på trening). *Husker du ordene som kom til slutt i de tre setningene* (kino – gule – bilen).

Prøveleder viser på tavla hvordan de åpne feltene skal fylles ut.

”Nå begynner vi på første ordentlig oppgave. Blyantene skal ligge på pulten til jeg har lest setningene og spørsmålet. Da sier jeg i fra at du kan ta opp blyanten og skrive svarene. Dersom du ikke husker alt, så skriver du bare det du husker. Hvis di ikke er sikker, kan du skrive det du tror det skal være. Legg fra deg blyanten når du har skrevet ferdig. Da vet jeg når alle er ferdig, og vi kan gå videre. Husk at det ikke er lov å samarbeide.”

1. serie:
- På middagsbordet sto det fem blå **kopper.**
- Bilen var gammel og begynte å få rust på **døra.**

Spørsmål: Hvilken farge var det på koppene?

2. serie:
- Line har tre bøker om katter, men ingen om **hunder.**
- I veien vår er det nesten bare røde **hus.**

Spørsmål: Hvor mange bøker om katter har Line?

3. serie:
- Per skal til Italia sammen med bestefar om en **uke.**
- Ole bor sammen med flere søsken, og alle er **jenter.**
- De har nettopp flyttet til **Halden.**

Spørsmål: Hvor skal Per sammen med bestefar?

4. serie:
- Ivar har bursdag i april, og han ønsker seg **bilbane.**
- Det er bare 6 jenter i klassen til **Kari.**
- Broren min bor på **loftet.**

Spørsmål: Hvor mange jenter var det i klassen?

5. serie:
- Etter 10 timer med regn, tittet endelig sola **fram.**
- I Sveits snakker de både tysk og **fransk.**
- Det beste Ola visste var grønne **druer.**

Spørsmål: Hvor mange timer hadde det regnet?

6. serie:
- Han har mange par sko, men ingen av dem er **blå.**
- Den røde ballongen sprakk da den traff **kaktusen.**
- Eleven kom alltid for sent til første **time.**

Spørsmål: Hvilken farge hadde **ballongen?**

7. serie:
- I byen er det 4 butikker som selger **bøker.**
- På fisketuren fikk vi makrell, som vi spiste når vi kom **hjem.**
- I bursdagen til Lars skal de ha pizza og **is.**
- I pennalet mitt har jeg to blå **penner.**

Spørsmål: Hva slags fisk fikk de på fisketuren?

8. serie:
- Fire venner dro på telttur til **Sverige.**
- I fjor kom snøen allerede i **oktober.**
- Tyven stjal en svart **moped.**
- Han fant ikke Moss på **kartet.**

Spørsmål: Hvor mange venner dro på telttur?

9. serie:
- Kristian spilte trompet hver **torsdag.**
- Han fikk 100kr av **bestefar.**
- Plommene som Maria spiste var gule og **søte.**
- Hun jogget 10 kilometer før **frokost.**

Spørsmål: Hvor langt jogget hun?

10. serie:
- På bondegården var det bare svarte **griser.**
- Kongen har livvakter som passer på ham hele **dagen.**
- Det lille epletreet hadde gule **epler.**
- På bløtkaka som mor bar inn var det 10 **lys.**

Spørsmål: Hvilken farge var det på eplene på det lille treet?

11. serie:
- På bordet sto det en vase med røde **roser.**
- Det var mange trær som hadde blåst ned i **skogen.**
- Petter fortalte at han hadde reist med tog i 14 **land.**
- På den bitte lille skolen var det bare 1 **elev.**
- Guttene sparket fotball hele **dagen.**

Spørsmål: Hadde Petter reist med buss, tog eller fly?

12. serie:

- Liv har langt brunt **hår.**
- I sommerferien var Sofie i **Paris.**
- Til jul ønsker jeg meg svarte **hansker.**
- Han la seg klokka ni hver **kveld.**
- Hver lørdag baker far **pizza.**

Spørsmål: Når la han seg?

Lytte – huske – skrive

Skriv svaret på spørsmålet som læreren stiller.

Skriv ned ordet som kommer sist i hver setning. Men vent til læreren har lest fersig alle setningene.

1. Svar på spørsmål: [ ]

Ord som kom til slutt: ____________ ____________

2. Svar på spørsmål: [ ]

Ord som kom til slutt: ____________ ____________

3. Svar på spørsmål: [ ]

Ord som kom til slutt: ____________ ____________

____

4. Svar på spørsmål: [ ]

Ord som kom til slutt: ____________ ____________

____

5. Svar på spørsmål: [ ]

Ord som kom til slutt: ____________ ____________

____

6. Svar på spørsmål: [ ]

Ord som kom til slutt: ____________ ____________

____

7. Svar på spørsmål: ☐

Ord som kom til slutt: ____________________ ____________________

____________________ ____________________

8. Svar på spørsmål: ☐

Ord som kom til slutt: ____________________ ____________________

____________________ ____________________

9. Svar på spørsmål: ☐

Ord som kom til slutt: ____________________ ____________________

____________________ ____________________

10. Svar på spørsmål: ☐

Ord som kom til slutt: ____________________ ____________________

____________________ ____________________

11. Svar på spørsmål: ☐

Ord som kom til slutt: ____________________ ____________________

____________________ ____________________

____

12. Svar på spørsmål:

Ord som kom til slutt:

I dette skjemaet finner du oppgaver med forskjellige påstander om temaer innenfor naturfag. Sett et kryss ved det svaret du tror er riktig i hver enkelt oppgave.

Sett bare <u>ett</u> kryss for hver oppgave.

1. D-vitamin kan redusere sjansen for…
☐ hjernehinnebetennelse
☐ kreft i indre organer
☐ astma
☐ sukkersyke

2. Ultrafiolett (UV) stråling kommer fra…
☐ grunnstoffet radon
☐ mobiltelefoner
☐ sola
☐ ozonlaget

3. De tre typene ultrafiolett stråling er…
☐ UV1, UV2 og UV3
☐ UVA, UVB og UVC
☐ UV-mikro, UV-makro og UV-mega
☐ UVX, UVY og UVZ

4. Om vinteren er det spesielt viktig å få i seg D-vitamin…
☐ fordi det er svakere sollys om vinteren
☐ fordi D-vitamin forebygger forkjølelse
☐ fordi det er kaldere om vinteren
☐ fordi D-vitamin sørger for jevn kroppstemperatur

5. Ultrafiolett (UV) stråling avhenger av…
☐ nærheten til basestasjonen
☐ temperaturen i jordas indre
☐ mineraler i grunnfjellet
☐ tykkelsen på skydekket

6. D-vitamin lages bare i kroppen når…
☐ vi trener
☐ kroppen utsettes for mikrobølgestråling
☐ hudcellene blir bestrålt med ultrafiolett stråling
☐ vi sover

7. I et solarium er det…
☐ røntgenstråling
☐ mikrobølgestråling
☐ gammastråling
☐ UV-stråling

8. Når vi bruker solarium…

- ☐ dannes vitamin C i kroppen
- ☐ dannes vitamin B i kroppen
- ☐ dannes vitamin D i kroppen
- ☐ dannes vitamin A i kroppen

9. Solstråler kan…

- ☐ forsinke hudens aldringsprosess
- ☐ føre til benskjørhet
- ☐ forårsake kreft i indre organer
- ☐ skade genetisk materiale i hudcellene

10. Sjansene for å få hudkreft er større…

- ☐ i Nord-Europa enn i Sør-Europa
- ☐ når en tar D-vitaminpiller enn C-vitaminpiller
- ☐ når en soler seg i solarium enn i naturlig sollys
- ☐ på land enn på sjøen

11. Du kan beskytte deg mot hudkreft ved å…

- ☐ være utendørs bare når UV-indeksen er høy
- ☐ bruke solkrem selv når det er overskyet
- ☐ få i deg nok C-vitamin
- ☐ mosjonere jevnlig

12. Det er to typer hudkreft. Den ene kalles basalcellekreft, den andre kalles…

- ☐ hudcellekreft
- ☐ psoriasis
- ☐ pigmentkreft
- ☐ føflekkreft

Integreringsoppgaver

- **Muntlig** svar

1) Forklar forholdet mellom soling, helse og sykdommer.
2) Kan flere enn ett syn på forholdet mellom soleksponering, helse og sykdommer være korrekte? Ja/ nei, hvis ja/ nei, hvorfor?