Demands and Cognitive Processes in Reading Digital Text

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ZUSAMMENFASSUNG

Wir leben im Informations- und Wissenszeitalter. Das geflügelte Wort „Wissen ist Macht“ ist dabei längst Realität geworden. Im 21. Jahrhundert ist vor allem derjenige mächtig, der sich auf den Umgang mit Informations- und Kommunikationstechnologien (engl. *information and communication technologies*, ICTs) versteht und fähig ist, sich mit ihrer Hilfe Wissen in beliebiger Form, Art und Weise anzueignen. Der Aufbau des World Wide Web hat enorm dazu beigetragen, Wissen zu strukturieren, aufzubereiten und für jedermann (mit Internetzugang) verfügbar zu machen. Scherzhaft heißt es heutzutage: „Man muss nicht alles wissen; man muss nur wissen, wo es steht.“ Die Art und Weise, wie Texte im Web strukturiert werden und zueinander in Verbindung stehen, verändert jedoch etwas in unserem Lesefluss und darin, wie wir Informationen verarbeiten und ihnen Sinn entnehmen. Diesem *Etwas* widmet sich die vorliegende Dissertation. Ausgehend von Anforderungen, denen sich Leserinnen und Leser digitaler Texte stellen müssen, untersucht sie individuelle kognitive Prozesse, die mit der Informationsverarbeitung einhergehen.

Hierzu wird im ersten Teil der Arbeit kurz in die Unterschiede zwischen linearen und nicht-linearen Text (sog. Hypertext) eingeführt. Hypertexte zeichnen sich dabei durch eine verzweigte Verbindungsstruktur zwischen einzelnen Textteilen (engl. *nodes*) aus. Diese Textteile sind untereinander durch Hyperlinks verbunden, über die sie angesteuert werden können. Das Auswahlprofil, in denen einzelne Textteile aufgerufen werden, wird hierbei als Navigationsverhalten bezeichnet. Entsprechend dieser Unterscheidung werden die Begriffe des linearen und digitalen Lesens eingeführt. Lesen ist nach konstruktivistischer Auffassung ein aktiver Prozess des Lesenden, in dem er ein propositionales Modell eines Textes mental erarbeitet und mit Wissen und Erfahrungen zu einem Situationsmodell anreichert. Demnach erfordert digitales Lesen, dass Leserinnen und Leser neben dem eigentlichen Leseprozess zusätzliche kognitive Ressourcen aktivieren, um mit den besonderen Eigenschaften von Hypertext angemessen umzugehen.

Im zweiten Teil werden zwei Forschungsfragen dargestellt. Diese wurden anhand eines Prozessmodells abgeleitet, das Lernergebnisse als Resultat eines komplexen Zusammenspiels aus individuellen Fähigkeiten, dem Hypertext als Lernunterlage und dem Verhalten des Lernenden beschreibt. Die erste Forschungsfrage konzentriert sich auf die Identifikation kognitiver Fähigkeiten, die das digitale Lesen konstituieren. Hierfür wurden schwerpunktmäßig vier Fähigkeitsbereiche betrachtet, die für die Bewältigung von

Anforderungen benötigt werden. Diese umfassen den Text selbst, Eigenschaften der Hypertextstruktur, die jeweilige Leseaufgabe und den Computer als Zugangsmedium. Im Konkreten wurden Hypothesen über die Zusammenhänge digitalen Lesens mit (1) Lesefähigkeiten auf Wort-, Satz- und Textebene, (2) Arbeitsgedächtnisfähigkeiten, (3) Fähigkeiten, Online-Informationen hinsichtlich ihrer Passung für bestimmte Leseaufgaben zu bewerten, und (4) basalen Fähigkeiten im Umgang mit Computerumgebungen formuliert. Daran anknüpfend thematisiert die zweite Forschungsfrage, wie die angenommenen Beziehungen des digitalen Lesens mit seinen Konstituenten erklärt werden können. Hierzu wurde insbesondere die Informationsauswahl, die Lesende durch ihr Navigationsverhalten treffen, als zentrale vermittelnde Variable betrachtet.

Zur Beantwortung der beiden Forschungsfragen wurden drei Studien herangezogen, die im dritten Teil der Arbeit zusammengefasst dargestellt werden. In diesen Studien wurden kognitive Prozesse des digitalen Lesens mit Hilfe von Daten aus der Nationalen Begleitforschung zur Einführung computerbasierten Assessments (CBA) im *Programme for International Student Assessment* (PISA) 2012 untersucht. Die erste der drei Studien konzentriert sich auf die Rolle, die das Arbeitsgedächtnis beim Lesen digitaler Texte einnimmt. Arbeitsgedächtnisfähigkeiten sind im Allgemeinen stark mit Lesefähigkeiten assoziiert, da sie für die Verarbeitung von Textinformationen und ihrer Verknüpfung mit Inhalten aus dem Langzeitgedächtnis zentral sind. Das Lesen digitaler Texte sollte aber neben dem mentalen Behalten und Verändern von Textrepräsentationen auch die Verarbeitung der strukturellen Beziehungen zwischen den Seiten eines Hypertextes erfordern. Es wurde daher untersucht, ob individuelle Fähigkeiten zur Aktualisierung von Gedächtnisinhalten (engl. *memory updating*) neben dem Verstehen linearer Texte für digitale Lesefähigkeiten prädiktiv sind. Um die Art des Zusammenhangs zwischen digitalem Lesen und dem Arbeitsgedächtnis näher zu spezifizieren wurden weitere Hypothesen über moderierende Einflüsse der Leseaufgabe, der Anzahl von Hypertextseiten und des Navigationsverhaltens formuliert.

Die Hypothesen wurden anhand einer Teilstichprobe von 288 Schülerinnen und Schüler (53% weiblich, M = 15.85 Jahre) überprüft, denen jeweils Aufgaben zum digitalen Lesen, zur Arbeitsgedächtnisaktualisierung sowie zum linearen Lesen vorgelegt wurden. Weitere Indikatoren wurden zum einen aus den Aufgaben zur Messung digitalen Lesens entnommen—pro Aufgabe die primäre kognitive Operationen zur Aufgabenlösung (engl. *reading aspects*) sowie die Anzahl von Hypertextseiten mit lösungsrelevanten (engl. *target nodes*) und irrelevanten Informationen (engl. *irrelevant nodes*). Zum anderen wurden

Logdaten verwendet, die während der Bearbeitung digitaler Leseaufgaben aufgezeichnet wurden. Gezählt wurde dabei, wie viele lösungsrelevante Seiten Schülerinnen und Schüler durchschnittlich fanden und wie häufig sie diese besuchten. Die Ergebnisse aus generalisierten gemischten linearen Modellen zeigten, dass Fähigkeiten zur Aktualisierung des Arbeitsgedächtnisses über den Effekt des allgemeinen Leseverständnisses hinaus die Lösungswahrscheinlichkeit der digitalen Leseaufgaben positiv hervorsagten. Dieser Effekt bestand vor allem für Aufgaben, die das Auffinden lösungsrelevanter Informationen erfordern. Der Effekt wurde weder durch die Anzahl lösungsrelevanter noch irrelevanter Seiten in einem Hypertext, aber durch das Navigationsverhalten von Schülerinnen und Schülern beeinflusst. Hierbei wurde er verstärkt, je mehr lösungsrelevante Seiten gefunden wurden. Sofern wiederholte Seitenbesuche beachtet wurden, verschwand diese Interaktion. Folglich profitierten Jugendliche beim digitalen Lesen von effizienten Arbeitsgedächtnisfunktionen—unabhängig davon, ob sie gute Leser waren oder nicht. Defizite des Arbeitsgedächtnisses wurden durch einen strategischen Umgang mit der Hypertextumgebung kompensiert.

Die zweite Studie behandelt Einflüsse von ICT-bezogenen Fähigkeiten. Als ICT-bezogene Fähigkeitsvariablen wurden basale Computerfähigkeiten sowie Fähigkeiten zur kritischen Bewertung von Online-Informationen hinsichtlich ihrer Relevanz und Nützlichkeit betrachtet. Unter der Prämisse, dass Jugendliche neben Lesefähigkeiten auch Grundkenntnisse über beziehungsweise Erfahrungen mit digitalen Umgebungen mitbringen müssen, um digitale Texte effizient zu lesen und zu verstehen, wurden Einflüsse des linearen Lesens sowie der beiden ICT-bezogenen Fähigkeiten erwartet. Weiterhin wurde vermutet, dass diese Zusammenhänge über die Informationsauswahl erklärt würden, die Schülerinnen und Schülern während des Lesens treffen (d.h. ihr Navigationsverhalten zu aufgabenrelevanten Seiten). Für den Zusammenhang des linearen und digitalen Lesens wurde dabei eine teilweise Mediation durch das Navigationsverhalten angenommen, da sich vor allem Prozesse zur Erarbeitung der Textkohärenz und der Integration von eigenem Wissen nicht in der Informationsauswahl niederschlagen müssen. ICT-bezogene Fähigkeiten sollten hingegen das Leseverständnis nur indirekt aufgrund individueller Erfahrungen mit Computerumgebungen begünstigen, sodass jeweils eine vollständige Mediation erwartet wurde.

Zur Untersuchung wurden die Daten von 888 Schülerinnen und Schüler (48% weiblich, M = 15.82 Jahre) herangezogen. Testwerte aus Aufgaben zum digitalen und linearen Lesen, zu basalen Computerfähigkeiten und zur Bewertung von Online-

Informationen wurden gemittelt zusammengefasst (engl. *item parcels*) und mit Hilfe von latenten Regressionen und Mediationsanalysen untersucht. Das Navigationsverhalten von Schülerinnen und Schülern zu aufgabenrelevanten Seiten wurde dabei über Aufgaben hinweg gemittelt und zu einer personenspezifischen Mediationsvariablen aggregiert. Die Ergebnisse bestätigten die Hypothese, dass Fähigkeiten im digitalen Lesen positiv und unabhängig durch Fähigkeiten im linearen Lesen, im basalen Umgang mit Computern und zur Bewertung von Online-Informationen vorhergesagt werden. Wie erwartet wurden dabei der Effekt linearen Lesens teilweise und der Effekt basaler Computerfähigkeiten vollständig durch das Navigationsverhalten vermittelt. Aus diesen Ergebnissen wurde abgeleitet, dass fähige Leser zielorientierter aufgabenrelevante Texte identifizieren und verarbeiten können, während routinierte Fertigkeiten im Umgang mit Computern sie dabei indirekt durch Wissen über die Funktionalität digitaler Benutzeroberflächen unterstützen. Entgegen vorheriger Annahmen war der Effekt der Fähigkeit zur Bewertung von Online-Informationen direkter Natur. Übermäßige Anleitungen in den Aufgabeninstruktionen sowie eine mögliche Mediation über Besuche irrelevanter Seiten wurden jedoch als potentielle Erklärungsansätze ausgeschlossen.

Die Bewertung von Online-Informationen und ihre Auswahl von Ergebnisseiten aus Suchmaschinenabfragen (engl. *search engine result pages*, SERPs) werden in der dritten Studie als Spezialfall digitalen Lesens herausgegriffen und gesondert betrachtet. Diese Studie untersuchte, welche Rolle Lesefähigkeiten auf der Wort-, Satz- und Textebene bei der Bewertung von Online-Informationen einnehmen. Dabei wurde von der Überlegung ausgegangen, dass individuelle Unterschiede in der kritischen Auseinandersetzung mit Informationen auf die Art und Weise zurückgehen, wie Jugendliche Textinformationen rezipieren und verstehen. Es wurden daher Hypothesen darüber formuliert, ob Zusammenhänge zwischen der Informationsbewertung und Lesefähigkeiten der Worterkennung, semantischen Integration und des Textverstehens bestehen. Von diesen Zusammenhängen wurde angenommen, dass sie durch die semantische Relevanz von Hyperlinks für eine Suchaufgabe und dem Navigationsverhalten zu anderen Seiten moderiert werden.

Dazu wurden die Daten von einer Teilstichprobe aus 416 Schülerinnen und Schülern (45% weiblich, M = 15.84 Jahre) untersucht. Für eine Reihe von Suchaufgaben wurden die Probanden gebeten, jeweils den nützlichsten Hyperlink von einer Suchmaschinenergebnisseite auszuwählen. Ihre Lesefähigkeiten auf der Wort-, Satz- und Textebene wurden anhand von lexikalischen Entscheidungsaufgaben, Satzverifikationsaufgaben und

Textverständnisaufgaben abgebildet. Ein Indikator zur semantischen Relevanz der Hyperlinks einer Suchaufgabe wurde durch die Varianz von Relevanzurteilen externer Rater (N = 7) gebildet. Das Navigationsverhalten wurde in Form von zwei dichotomen Variablen erfasst. Diese gaben an, ob Schülerinnen und Schüler andere Suchmaschinenergebnisseiten oder verlinkte Webseiten besucht hatten. Analysen mit generalisierten gemischten linearen Modellen zeigten Effekte der Lesefähigkeiten auf die Bewertungsfähigkeit. Dabei leisteten solche auf Satz- und Textebene einen unabhängigen Beitrag leisteten. Lediglich die Effekte des Textverstehens variierten in Abhängigkeit von der semantischen Ähnlichkeit der Hyperlinks zueinander und dem Navigationsverhalten zu anderen Suchmaschinenergebnisseiten. Die Interaktionen der Lesefähigkeiten mit dem Verhalten, zu verlinkten Webseiten zu navigieren, zeichneten ein anderes Ergebnismuster ab. Verblieben Jugendlichen auf einer Suchmaschinenergebnisseite, waren ihre Worterkennungsfähigkeiten für ihre Hyperlinkauswahl prädiktiv; suchten sie verlinkte Webseiten auf, zeigte sich ein Effekt des Textverstehens. Die Ergebnisse wurden dahingehend interpretiert, dass Lesefähigkeiten auf der Wort-, Satz- und Textebene unterschiedliche Auswahlstrategien bei der Bewertung von Online-Informationen unterstützen. Kompetente Leser sind hierbei in der Lage, ihre kognitiven Ressourcen effizient zu verteilen.

Im abschließenden vierten Teil der Arbeit werden grundlegende kognitive Prozesse der Informationsverarbeitung digitalen Textes diskutiert. Als Resultat der gemeinsamen Betrachtung der drei vorgestellten Studien erscheint digitales Lesen hierbei als komplexes Fähigkeitsgemisch. Dieses beruht auf allgemeinen Lesefähigkeiten, auf einer effizienten Allokation kognitiver Ressourcen, auf der strategiegetriebenen Vorhersage von Informationen und auf rudimentären Fertigkeiten im Umgang mit Computerumgebungen. Dabei beschreibt digitales Lesen kein neues, aber ein zeitgenössisches Konstrukt, das sich als Reaktion auf aktuelle individuelle und gesellschaftliche Informationsbedürfnisse entwickelt hat und sich entsprechend der fortschreitenden technischen Weiterentwicklung verändern wird.

Whether we’re ready or not, the Knowledge Age has arrived.

Trilling & Fadel (2009). 21st Century Skills: Learning for Life in Our Times.

INTRODUCTION

In a world where it is natural for many people to use computers, tablets, or mobile devices to access the World Wide Web (WWW) and just to look up something quickly, knowledge seems to be omnipresent. Services like search engines, wikis, clouds, or instant messengers are commonly used and illustrate how many people deal with information and communication technologies (ICTs) to synthesize, evaluate, communicate, create, and share information (Leu, Kinzer, Coiro, & Cammack, 2004). Since society is changing towards an information and service orientation, written information has become available in a larger amount and a more complex form than ever before (Rammstedt et al., 2013; Zumbach, 2010). Knowledge has been bundled progressively, tied to digital media and distributed over digital nets (Iske, 2002). Digitalization has certainly facilitated this development and presents new challenges for information selection and processing (Bos, Eickelmann, & Gerick, 2014).

One major challenge relates to the representation of information in a non-linear text structure that influences how information is read (e.g., Coiro, 2011; Zumbach & Mohraz, 2008). Reading requires individuals to receive and process information from a text itself while simultaneously retrieving information from their long-term memory in order to put the text's information into an appropriate context (Groeben, 1982; Kintsch, 1998). Thus, reading is often considered as a construction process that consists of semi-hierarchically organized constituents, including bottom-up (e.g., decoding words) as well as top-down processes (e.g., drawing inferences, making meaning) (Perfetti, 2007; Perfetti & Stafura, 2014). Text comprehension is considered to be reflected in a mental representation that readers create by integrating the text information (i.e., a mental model of the text base) with their own knowledge and experiences (i.e., a mental representation of the situation) (Johnson-Laird, 1980; Kintsch, 1998). This situation model is supposed to be influenced in a task-driven way and, therefore, always situated within a particular context (Rouet, 2006). Hence, reading cannot occur passively. Rather, it is an active process of text processing based on internal cognitive processes. Although it often takes place casually, without being perceived as activity (e.g., reading price tags or traffic signs), reading is indispensable for the purposive search of written information (Rammstedt et al., 2013).

Reading enables individuals to fulfill private, educational, and occupational—in short, everyday—needs of life (Klieme et al., 2010). As such an essential prerequisite for lifelong learning, communication, and participation in society (Boland, 1993), reading is often examined with the intention to prepare children and adolescents for the challenges of adult life. Accordingly, student reading competencies are seen as an important evaluation criterion of education systems worldwide, which makes their assessment an integral part in educational large scale assessments (LSAs) like the *Programme for International Student Assessment* (PISA; Organisation for Economic Co-operation and Development [OECD], 2013). PISA in particular investigates the knowledge, skills, and attitudes of 15-year-old adolescents, who are approaching the end of compulsory education and will enter professional life soon.

Due to the technological developments and their growing role in everyday needs, though, reading behavior has changed and includes increasingly digital besides printed texts. Especially young people are active users of digital technologies (e.g., Bos et al., 2014). Within 15 years, the proportion of German adolescents having their own computer increased continuously from 35% in 1998 up to 80% in 2013 (Feierabend, Plankenhorn, & Rathgeb, 2013). In 2016, 96% of the 12- to 19-year-olds reported to make use of it at least several times a week (Feierabend, Plankenhorn, & Rathgeb, 2016). A similar picture was shown internationally (OECD, 2011), where computer access in OECD countries was reported by 72% of students in 2000 and 94% in 2009. Internet access reached 45% in 2000 and 89% in 2009. With respect to adolescents‘ use of the computer, communication activities accounted for the biggest share (40%), followed by entertainment (26%), online gaming (20%), and seeking for information (14%; Feierabend et al., 2013). With increasing age, adolescents also reported to use information from search engines, wikis and news portals as tools for learning and carrying out school-related tasks.

In all these activities, students usually encounter digital text information in a non-linear structure—so called hypertext—that has specific characteristics and functionalities. Demands resulting from these structures, though, interact with the complex nature of reading as a process of information reception, which can seriously affect text comprehension (DeStefano & LeFevre, 2007; Zumbach, 2010). Based on this background, this work investigated individual differences in information processing and text comprehension of digital hypertext. Therefore, reader-text interactions are examined that result from individuals' cognitive skills and requirements of hypertext. The following part briefly introduces the concept of hypertext and gives a short overview on digital reading. The second part summarizes research questions concerning the interplay of individual cognitive prerequisites and digital hypertext structures. Three studies that investigated cognitive processes in reading and engaging with digital text are introduced in the third part. They are used in the fourth part to answer the research questions and to derive theoretical and practical implications.

1. PROCESSING DIGITAL TEXT

1.1 Hypertext

True to the adage "old but gold", hypertext boomed as a structure to organize and represent text through the development of modern ICTs, although it has been known for centuries as a reference and mapping system (Gall & Hannafin, 1994; Iske, 2002; Kuhlen, 1991; Rouet, Levonen, Dillon, & Spiro, 1996). Hypertext is based on the non-linear organization of individual text units—so called nodes or pages—that are connected and accessible via (hyper)links. Single nodes contain information on a particular topic that should be inherently consistent. In contrast to nodes, hyperlinks mainly serve to relate nodes among each other. Semantically close nodes are typically linked directly. In addition to their function of connecting, hyperlinks should also create transparency for hypertext users by allowing for anticipating the content of upcoming nodes. Especially in digital formats, several link types can be differentiated that signalize different characteristics and functionalities to users and regulate user behavior in that way (cf. Naumann, Richter, Flender, Christmann, & Groeben, 2007). For example, referential links are based on formal syntactic (e.g., forward and backward links signaling page turns) or associative principles ("has to do with ...", e.g., cross-references), whereas semantic links operate at the content level. Differentiation can also take place on a functional (e.g., the link target position is within a node vs. between nodes) or surface level (e.g., arrows as symbolic representations).

At this point, some terminological distinctions need to be introduced. To emphasize differences in text handling, hypertext is often compared to linearly structured text, whereas the distinction between print and digital/electronic mainly refers to the text presentation mode (cf. Rouet, 2006; Rouet & Levonen, 1996). Table 1 gives an overview and examples for specific combinations of linear and hypertext structures in print and digital presentations. Linearly structured text refers to a self-contained text form whose structure and flow has been explicitly specified by an author. Readers are guided through the text by the author's intention and arguments build on each other. This can also include discontinuous text formats like tables or graphs. Printed books are often considered as prototypes for linear text. This is why print reading is sometimes used synonymously with linear reading, although linear text can be presented digitally too. Similarly, hypertext formats are not restricted to digital ICTs, but their usage has been facilitated due to the introduction of computers. Mixed forms and gradual nuances from linear to hypertext make it difficult to give clear definitions, but they are natural either in a digital or a printed format. In this regard, nodes containing large amounts of text can mask the hypertext principle so that the impression of a linear text is produced. For example, a single online newspaper article can be seen as a self-contained linear text. Regarding the overall structure of a newspapers' website with other articles accessible via cross-references, though, it can be seen as a hypertext.

Especially the online newspaper example points at the scope and significance of reader–text interactions. Readers decide how they read text. Even when they deal with linear texts, readers choose on their own to read it in a given linear order or to jump between text parts in a non-linear fashion. In hypertext, though, the choice and sequence of node reception is not predefined but only suggested by a content author. Due to the fragmentation of information, fewer cues can be provided about what information to process next and where to find it (Foltz, 1996). Therefore, decisions about the reading order fall increasingly on the reader. The metaphor of navigation is hereby frequently used to describe a reader's movement through the nodes of a hypertext system (Lawless & Kulikowich, 1996; Lawless & Schrader, 2008). In that, navigation behavior reflects

Table 1

Examples of texts differing in structure and presentation mode

		text structure	
		linear	**hypertext**
presentation mode	**print**	printed narratives, educational books	dictionaries, encyclopedias
	digital	eBooks, single articles in online newspapers	blogs, forums, cross-references in online newspapers

whether readers access nodes and, if so, how they arrange them for gaining information. Consequently, navigation is an expression of how readers interact with a hypertext structure and how they create their own text base (Zumbach, 2010).

Dealing with hypertext is usually an issue of task-oriented search of information as well as an issue of navigation that is required because of the missing reading guidance (Foltz, 1996; Rouet, 2006). Potential consequences of information overload and disorientation ("lost in hyperspace") are often discussed from a system and a user-centered perspective on hypertext (Iske, 2002; Rouet et al., 1996). While a system-centered perspective focuses on the invention and implementation of hypertext techniques (e.g., architectures, machine processing routines), the user-centered perspective examines skills that are required to use a hypertext system and effects of hypertext on readers' activities. Another terminological distinction is often made between hypertext and hypermedia (Kuhlen, 1991). Hypermedia is usually used to emphasize the inclusion of pictures, audios/videos and animations that can influence information processing and the construction of a mental representation of a text situation (e.g., Horz & Schnotz, 2008; Schnotz, Ludewig, Ullrich, Horz, McElvany, & Baumert, 2014).

This work takes a user-centered perspective and focuses on the comprehension of hypertext presented digitally. It examines influences of individual cognitive skills on hypertext comprehension and their interplay with situational characteristics. Although the studies that are presented in the second part operate on hypermedia material (PISA 2012 Digital Reading Assessment; OECD, 2013), this work concentrates on how readers are processing and comprehending written information. The term *linear reading* is used to refer to reading activities that mainly involve linearly structured text—independent of a printed or digitalized presentation. In accordance with the terminology that is used in the PISA 2012 study, the term *digital reading* is used to refer to reading activities that take place in a digitally presented hypertext environment and, therefore, can require interactivity between text and readers such as navigation. The next section will briefly review research on digital reading and highlight specific demands individuals need to meet when reading a hypertext.

1.2 Assumptions regarding the Digital Reading Process

Based on the idea that associative principles in hypertext structures would simulate human cognition better than ever possible in linear text (Jonassen & Wang, 1993), computer-assisted learning was often seen as an aid to promote literacies in new and personalized ways (Foltz, 1996; Leong, 1992). Research on this matter especially experienced a heyday in the 1990's (e.g., Gall & Hannafin, 1994) and goes on until today. A major focus was often made on the comparison of linear and digital reading, asking in which format learning will be most effective (e.g., Lee & Tedder, 2003; Zumbach & Mohraz, 2008). The digital revolution has affected the quantitative amount of available text as well as qualitative aspects of text (Iske, 2002; Leu et al., 2004). Cognitive resources in humans are not infinite, though (Feldman Barrett, Tugade, & Engle, 2004), making it necessary to deal with the overabundance of information in an efficient way.

In order to describe how individuals deal with hypertext resources, Naumann (2012) introduced a general model on hypertext learning. This model describes learning outcomes as the result of an individual's processing behavior, person-related resources, and text-related demands (Figure 1). In the specific context of digital reading, it means that individual variables (e.g., reading skill level) as well as characteristics of the reading situation (e.g., instructions) will indirectly influence text comprehension as an outcome of reading by affecting and modulating the reading process. The reading process is determined by information selection, processing, and sequencing—often operationalized through navigation behavior—since readers' interactions with hypertext pages set the limits for their operative text basis and input. Accordingly, indicators of navigation usually strongly predict readers' performance in digital reading and were found to be affected, for example, by linear reading skills (e.g., Naumann, Richter, Christmann, & Groeben, 2008; Naumann & Salmerón, 2016; Salmerón, Cañas, Kintsch, & Fajardo, 2005; Salmerón & García, 2011). Beside the mediational presumptions, the model integrates the concept of aptitude–treatment interactions that are based on the idea that instruction needs to fit the individual skills of a learner (cf. Plass, 2005). Hence, the relations of text-specific demands with processing behavior and text comprehension are supposed to be moderated by individual variables. In accordance, reading skills were found, for example, to influence the perception and use of surface and semantic cues in texts (e.g., Naumann et al., 2007; Rouet, Ros, Goumi, Macedo-Rouet, & Dinet, 2011).

Naumann's model (2012, Figure 1) gives an overview on processes and influences that affect comprehension of digital text. However, trying to think of a 'typical' digital reading situation demonstrates that digital reading strongly depends on the circumstances in which it takes place. Readers, for instance, using a search engine to look up facts (e.g., capitals of Europe) will construct and manage their reading process in a very different way than readers browsing a blog for latest news. Although readers in both examples need to decide what to read without an author's expertise and guidance, they have different objectives to accomplish and deal with texts varying in style, architecture, and functionality. Anchored in our knowledge of human cognitive structures and their relevance for instruction, Sweller and colleagues (e.g., Sweller, Ayres, & Kalyuga, 2011) formulated a theory of cognitive load that basically differentiates between load originating from the nature of instructional material (e.g., a text) and the nature of instructional design (e.g., presentation of text, navigational requirements on readers). In that, Rouet (2009) identifies three sources that impose cognitive load on working memory in hypermedia learning activities: individual variables, involved information resources, and the task. Similarly to Naumann's (2012) model, activities of learners are shaped by their individual characteristics (e.g., prior knowledge, general cognitive, and linguistic skills) and the information resource as an environment in which learning takes place (e.g., texts, software, also human peers and tutors). Yet, Rouet emphasizes the task context as driving learners' attention to information by determining relevance criteria for information and situational constraints (e.g., available time, expected benefit). Researchers generally agree that digital readers will experience an increased cognitive load due to the additional requirements of decision making and navigation over and above processing a text itself (DeStefano & LeFevre, 2007). Nevertheless, specific reading settings depending on the hypertext, the environment, and the task will confront readers with different activities requiring different cognitive processes.

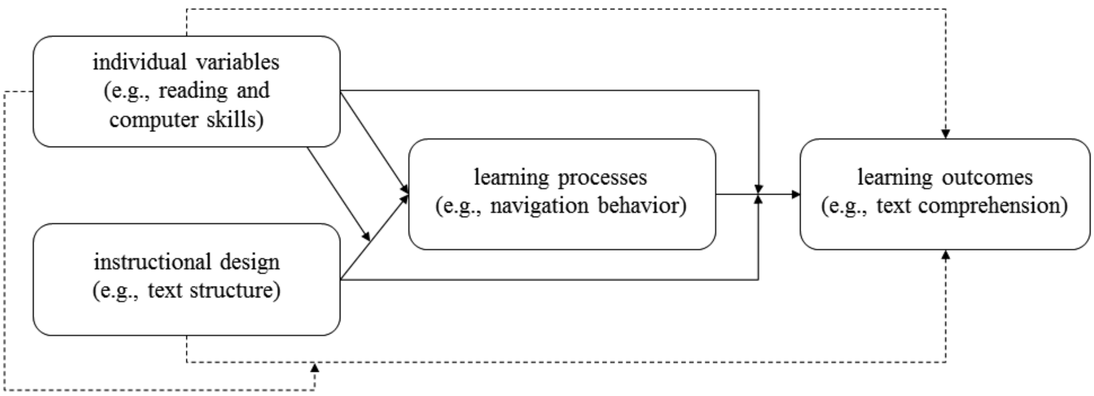

Figure 1. Model of influential factors and skills on processes and outcomes of digital reading (adapted from Naumann, 2012).

Based on this background, I propose to differentiate between demands of the text, the hypertext structure, the task, and the medium. Such categories are not meant to be disjunctive. Several demands are intertwined and boundaries are fluid (e.g., having specific requirements on text versions and their organization for computers and mobile devices). Rather, this classification aims to support the identification of relevant cognitive processes that are involved when individuals read digital text. The following parts briefly summarize the mentioned classes of demands that can affect digital reading as well as the cognitive processes required.

1.2.1 Text Related Demands

Regardless of all specificities of digital text, the demand to process written information in digital reading strikes one immediately. The orthography, phonology, and morphology of words need to be decoded and identified in order to retrieve their meaning from the mental lexicon (Perfetti & Stafura, 2014). Parsing the syntactic structure in which words are organized and integrating their meanings then allows readers to construct mental text representations. Hereby, different processes in reading on word, sentence, and text level have to work together enabling readers to form a propositional text model and a knowledge-enriched situation model (Groeben, 1982; Kintsch, 1998). In that, linear reading and digital reading share a lot of basic principles and processes (Foltz, 1996). Accordingly, linear reading and digital reading were often found to be highly correlated. In PISA 2009 (OECD, 2011)—the first PISA cycle in which digital reading was assessed—correlations varied between .71–.89 for the individual participating countries. This could be replicated for when Germany participated in PISA 2012 for the first time in the digital reading assessment (Naumann & Sälzer, in press). The correlation between linear and digital reading was .80, with respect that linear reading correlated even higher with other competencies (.87 for mathematics and .90 for science). As a result, it was often concluded that although digital reading is clearly related with linear reading skills, both proficiencies cannot be used interchangeably (e.g., Afflerbach & Cho, 2008; Leu et al., 2004; Naumann & Sälzer, in press).

1.2.2 Structure Related Demands

The architecture of hypertexts and how they represent relationships between nodes place particular demands on the way in which readers will locate information and establish coherence between nodes. In a broader sense, coherence refers to the meaningfulness of a text or, more precisely, to readers' interpretations of concepts and their connections in text sections. Text authors usually aim at conveying text in a coherent form to readers supporting them to relate text information on a content level (Foltz, 1996). Without a coherent mental representation of the text, readers can quickly become disoriented and fail to locate information needed (Boechler, 2001; Lawless & Schrader, 2008). In linear text, coherence arguments are typically given throughout the text (e.g., by the flow of paragraphs). In hypertext, though, jumps between nodes enforce readers to make bridging inferences that are necessary to "incorporate the textual information from the new node into what has been previously read" (Foltz, p. 116). Therefore, in order to represent the text structure readers are required to make navigational decisions and integrate new nodes into a relational context to other nodes. These requirements produce more cognitive load for readers than in linear text (DeStefano & LeFevre, 2007; Scheiter, Gerjets, Vollmann, & Catrambone, 2009) and lead to the assumption that indicators of readers' navigation are important predictors of hypertext comprehension and knowledge acquisition (e.g., Naumann, 2012; Naumann & Sälzer, in press; Salmerón & García, 2011). In this regard, for example, different versions of concept maps and hypertext overviews (e.g., hierarchical, relational, spatial) have been frequently investigated as aids of representing text structure (e.g., Amadieu, van Gog, Paas, Tricot, & Mariné, 2009; McDonald & Stevenson, 1998; Möller & Müller-Kalthoff, 2000; Müller-Kalthoff & Möller, 2005; Scott & Schwartz, 2007). They were shown to have influence on readers' experience of cognitive load, but effects on comprehension strongly depended on how readers navigated through a hypertext (Salmerón et al., 2005).

1.2.3 Task Related Demands

Hypertexts allow for multiple possible paths between nodes. However, it is unlikely that readers will walk through every single combination since they usually try to use a hypertext according to a specific reading purpose. Herein, readers are challenged to permanently re-evaluate their current text comprehension and decide if they need more information to fulfill a specific task and where to find it (Lawless & Schrader, 2010; Leu et al., 2004; Wenger & Paine, 1996). On their way, readers can encounter unhelpful, unnecessary, or distractive information for a task at hand. Therefore, they are in need of selecting information strategically and making informed guesses about unknowns including particular links, node contents, and solution paths (Afflerbach & Cho, 2008). In light of this, digital reading as the skill to locate, evaluate, and use hypertext information can be seen as problem solving process (cf. IPS model, Information Problem Solving on the Internet; Brand-Gruwel, Wopereis, & Walraven, 2009; Lazonder & Rouet, 2008) since readers need to develop heuristics and make predictions that fit the demands of a preexisting task.

The critical evaluation of information is a necessary precursor for determining the relevance of information for a task at hand. Based on internal needs (e.g., background knowledge and cognitive skills; Coiro & Dobler, 2007; Kuhlen, 1991) and environmental constraints (e.g., accessibility of information), readers will construct a model of a particular task determining how they perceive information relevance (Rouet, 2006). Credibility judgments in terms of information quality and authority (Rieh, 2002) are also often seen as important aspects in relevance assessment (Hilligoss & Rieh, 2008). Especially skilled readers are supposed to be better at exploiting cues in form and structure, enabling them to generate better hypotheses about text meaning as they read through (Foltz, 1996). This corresponds to models of web navigation (e.g., CoLiDeS+, Juvina & Oostendorp, 2008; SNIF-ACT, Fu & Pirolli, 2007). They predict that digital readers will make subjective predictions about the content relatedness to other distal nodes based on proximal cues (e.g., link labels). With the assumption of mechanisms of spreading activation, nodes are likely to be regarded when links convey a high content based overlap (high *information scent*). In contrast, readers will not follow a link or leave a website when information scent diminishes below a particular threshold. Accordingly, differences of hypertext use and style of navigation were found depending on the task. Compared to open hypertext exploration, for example, readers pursuing a directed task made use of maps and overviews more often, were faster in searching for particular information, but also showed lower comprehension on general knowledge questions (Foltz, 1996). The more specific the reading task, the more context will be maintained around specific required information.

1.2.4 Medium Related Demands

Last but not least, the specific medium or environment that readers use to interact with text can put certain demands on them. Representational effects of media as delivery systems are often investigated in terms of evaluations of the usability of particular systems (e.g., screen resolution or surfaces; cf. Chen, Fan, & Macredie, 2006; Rouet et al., 1996) or comparisons of test outcomes between different assessment modes (e.g., Bürger, Kröhne, & Goldhammer, 2016; Kröhne & Martens, 2011). Both research traditions reveal differences in (text) processing that are due to the particular medium of administration. To get along with variable digital interfaces—independent of versions (e.g., browsers: Firefox vs. Internet Explorer vs. Chrome), students are required to possess general concepts about structures and functionalities in computer environments (e.g., using navigation aids, using mouse and keyboard, using prototypical software interfaces). Although digital media are more widespread than ever before and students got more familiar with digital environments across the last decade (Feierabend et al., 2013), studies like the International Computer and Information Literacy Study (ICILS; Fraillon, Ainley, Schulz, Friedman, & Gebhardt, 2014) attest most students basic computer skills and knowledge rather than a competent and reflective use of information with the aid of computers. Yet, a regular use of ICTs is not a part of daily school life (Bos et al., 2014). The mere availability of computers is not synonymous with being able to use them efficiently. For example, Naumann and Sälzer (in press) revealed a negative quadratic trend of ICT availability at home and at school on digital reading. Beginning flat, the prediction of digital reading skills grew more and more negative with an increasing availability of ICTs at home and at school. It shows that access is not a privilege anymore. Nevertheless, skills in using digital devices appropriately are highly in need to access, manage, and comprehend information online (Gall & Hannafin, 1994).

2. RESEARCH QUESTIONS

The effectiveness of hypertext systems for learning purposes is often discussed and there is common sense that the specific characteristics of hypertext place additional cognitive demands on readers in terms of decision making, navigation, and orientation (e.g., DeStefano & LeFevre, 2007; Plass, 2005; Rouet, Vörös, & Pléh, 2012). Cognitive skills have been investigated as resources or modulators that readers need in order to benefit from hypertext learning. Naumann's (2012) process model gives a fundamental conception of the interplay between individual cognitive skills, hypertext design, and comprehension in digital text. Being supported by specific instructional aids and strategies in dealing with hypertext (e.g., Amadieu et al., 2009; Naumann et al., 2007), cognitive skills were found to determine the individual perception of cognitive load. Specific mechanisms of how particular cognitive skills constitute hypertext reading, though, were only partly focused (e.g., Coiro & Dobler, 2007; Naumann et al., 2008; Rouet et al., 2011; Salmerón & García, 2011). To shed light on the complex nature of digital reading and involved cognitive processes, this work investigates how individual differences in students' cognitive skills influence their information processing and comprehension of digital text, raising the following two research questions.

1. What are cognitive constituents of digital reading skills?

As mentioned, readers of digital text will encounter many different demands originating from the text itself, structural conditions, task requirements as well as medium related specifics. Based on these demands, there should be several constituent skills determining how readers will deal and engage with hypertext. In the context of this dissertation, I investigated skills that were expected to meet these demands and, therefore, be of particular relevance—namely general reading skills on word, sentence, and text level as well as working memory, evaluating online information, and basic computer skills.

(1) General reading skills on the word, sentence, and text level are clearly essential to meet several demands raised by a text itself. Whether reading a digital or linear text, underlying mechanisms of decoding, word-text-integration, and meaning extraction are the same (e.g., OECD, 2011; Salmerón & García, 2011). By interpreting and using semantic cues, skilled readers are able to establish coherence between different text parts (e.g., between text and links, or between nodes) and form an understanding of even fragmented text or lose sections. Therefore, reading skills measured with linear texts are expected to explain a large share in digital reading comprehension.

(2) Increased demands in relating information between different nodes are due to the organization of hypertext. Since there are less contextual cues signaling the extent and connection of text parts, readers are challenged to form a structural representation about hypertext. In that, working memory should play a crucial role for readers over and above their linear reading skills. As processing resource, it provides the capacity to deal with more than text information. Accordingly, previous studies have formed the idea that digital readers construct a spatial representation of nodes and keep it up-to-date as they read (Pazzaglia, Toso, & Cacciamani, 2008; Rouet et al., 2012). Therefore, working memory was expected to account for digital reading over and above linear reading skills.

(3) Although it seems desirable that readers will deeply elaborate on every detail in a hypertext system, they are more likely to skim information and apply reading strategies along their reading purpose (Coiro & Dobler, 2007; Evans, 2008; Lawless & Schrader, 2008). To locate information and plan their reading progress, readers need to make predictions and anticipate node contents. Although general reading skills will support readers' understanding of the text, the lack of contextual cues will enforce them to generate hypotheses and make predictions about upcoming content more often than in linear text. Readers need to evaluate and reflect on several aspects of information usefulness in order to make an informed guess about the appropriateness of information for a reading task at hand. Skills in evaluating online information from search engine result pages can be considered to work as proxy for predicting the usefulness of information since they describe how readers use structural and message-based cues of hyperlinks in order to judge the relevance and credibility of upcoming information (Goldhammer, Keßel, & Kröhne, 2013). Therefore, being skilled in the evaluation of online information is expected to be an important prerequisite in proficient digital reading over and above linear reading.

(4) On a macro-level that concerns hypertext comprehension rather indirectly, computers as an administration medium will require readers to possess skills to deal adequately with particular functionalities. Basic computer skills enable them to interact with computers for accessing, collecting, and managing information (Goldhammer, Naumann, & Keßel, 2013). This can concern the usage of mouse and keyboard, knowledge about structures and functionalities (e.g., clicking the home button means return to start page) as well as dealing with particular software applications (e.g., text editors, email clients, browser interfaces). Therefore, basic computer skills are expected to be indirectly, but essentially related to digital reading tasks that involve such interface functions.

2. How can the relations between digital reading and its constituent skills be explained?
Cognitive skills are expected to affect digital text comprehension not only directly (Naumann, 2012). Rather, they can influence the actual behavior of readers, resulting in effects on digital text comprehension. A crucial component in the process of digital reading is the selection of information. By navigation, readers actively construct their own text that determines their information base (e.g., Lawless & Schrader, 2008). Therefore, finding relevant information is considered as a product, but also a condition of effective navigation

and text comprehension. This process is expected to be differently related to the cognitive constituent skills identified under the first research question.

(1) Proficient reading skills are supposed to support readers in identifying relevant information. Using semantic cues, readers will be able to locate particular information as they read along (Salmerón et al., 2005). Information selection, though, is just one step in digital text comprehension. Readers need to make sense of text by maintaining coherence across nodes and filling missing information by their own knowledge (Foltz, 1996). Therefore—and in accordance with findings for sixth graders (Salmerón & García, 2011)—linear reading skills are expected to affect digital reading directly as well as indirectly through readers' information selection.

(2) The more information is encountered and needed to answer a particular reading task, the more demands will be made on working memory. New nodes potentially require to store, evaluate, and—depending on the node content—to compare new information with existing information. While reading is processed, working memory skills will be an aid for keeping information active in terms of context, accuracy, and topicality. In that, working memory resources can also be relieved. Using compensating reading strategies like rereading or reactivating relevant information can alleviate deficits in working memory skills. Therefore, the relationship of working memory and digital reading is expected to interact with readers' navigation behavior.

(3) In terms of assessing the relevance of information, skills in evaluating online information will support students in decision making about what information is necessary to answer a particular search question. However, this might not be directly reflected in students' access and selection of hypertext nodes. When readers can already infer from a particular link whether an upcoming node is relevant or not (e.g., *About* or *Contact* links reveal author information), they will only click the link and construct a corresponding pathway if the information is needed. If they cannot predict the relevance from the link, though, they will need to access the node and then decide about its usefulness for a task at hand. Therefore, the effect of skills in evaluating online information on digital reading will not be explained through readers' information selection.

(4) As a skill that enables students to access and collect information across different computer environments, basic computer skills will guide readers in using a current software interface practically to gain access to particular information. Thus, readers' comprehension will not be supported in terms of fundamental processing and integration of

information, inferencing, or meaning making. Rather, comprehension will get indirectly facilitated by making it possible for readers to use computer interfaces for accessing and relocating information flexibly.

3. SUMMARY OF THE STUDIES

In the following, the three studies of this dissertation are briefly presented to answer the research questions raised. Each of them investigated skills and cognitive processes that are involved when 15-year-old German students read and engage with digital text. The first two studies are based on a broad conceptualization of digital text, including options to navigate between nodes and tasks that required using these options. The third study specifically focuses on search engine results as a special form of hypertext. The studies are based on data subsamples originating from the computer-based study parts in PISA 2012—namely, the international PISA computer-based assessment (CBA) and an accompanying CBA add-on study conducted in Germany. Before the studies are summarized, the next section will briefly introduce the sampling procedure, the underlying design, and the measures.

3.0 Sample, Design, and Measures

PISA study assesses the competencies of 15-year-olds in reading, mathematics, and science in a 3-year cycle in order to assess indicators of educational systems by monitoring and comparing student competencies (PISA 2012 main study; OECD, 2013). In 2012, Germany additionally participated for the first time in the CBA option in PISA that added measurements of digital reading, CBA of mathematics, and complex problem solving (PISA 2012 CBA). In order to deeply examine conceptual and methodological effects of CBA implementations in PISA, a third study part was exclusively carried out in Germany (German CBA add-on study).

For the selection of a representative student sample, a two-stage sampling procedure is applied in PISA (OECD, 2014). In this procedure, PISA-eligible schools including 15-year-olds are sampled at first. In the second step, random samples from all 15-year-olds at these schools are drawn. In Germany, 247 schools and from each school 25 students were drawn randomly to participate in PISA 2012 (upper left part of Figure 2). The realized

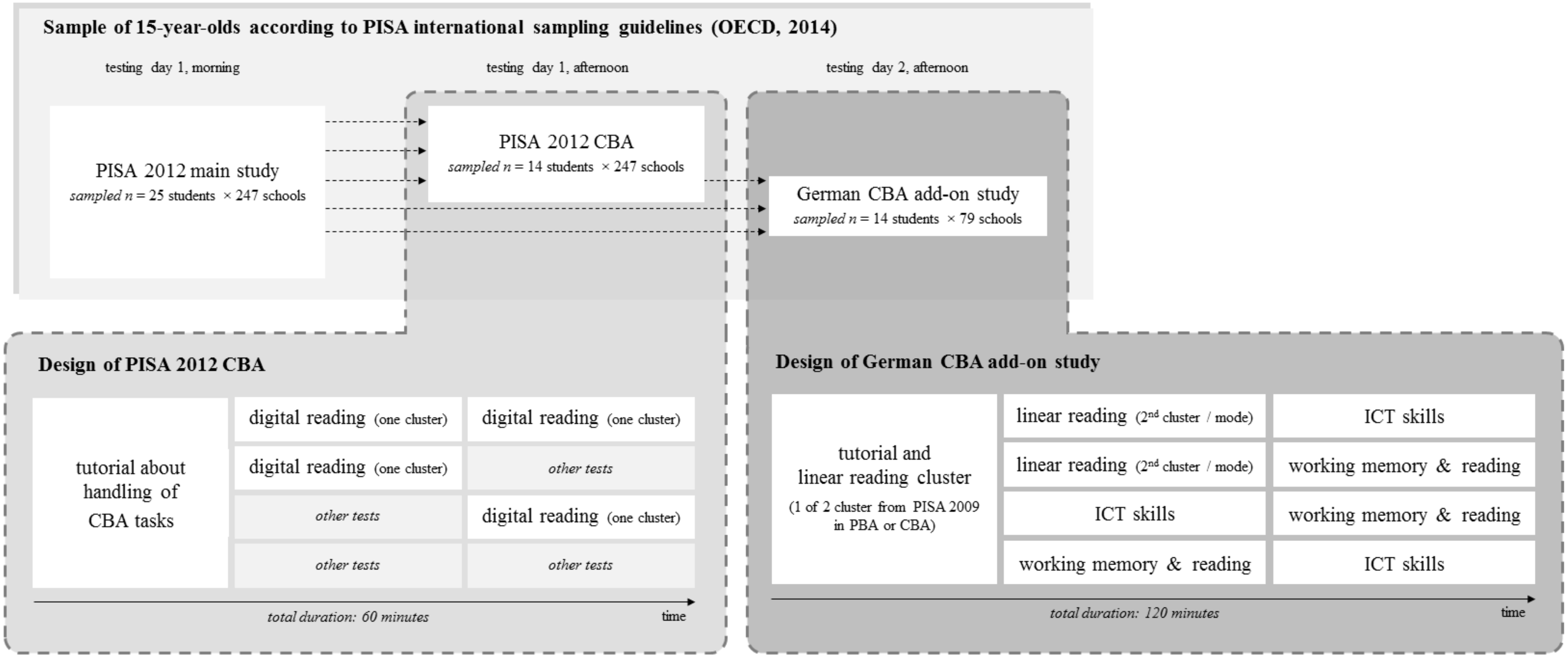

Figure 2. Sampling and Design of PISA 2012 CBA (Heine et al., 2013) and the CBA add-on study.

sample size was 5,001 students from 230 schools (Heine, Sälzer, Borchert, Sibberns, & Mang, 2013). From this pool, random subsamples were drawn to participate in the additional study parts (i.e., PISA CBA and the add-on study). The chance to participate in PISA CBA was nearly about 50% (realized sample size = 2,881 students from 230 schools). For the add-on study, it was about 20% (realized sample size = 888 students from 78 schools). Since both samples were random subsamples from the PISA main sample, the chance to participate in both PISA CBA and the add-on study was about 10% (overlapping sample size = 856 students from 78 schools). Due to the design of the study parts, the realized sample size of students participating in the digital reading assessment as well as in the add-on study included 444 students from 77 schools. The design of the CBA study and the add-on study are described in the following (lower part of Figure 2).

Students participating in PISA CBA were asked to perform a 20-minute tutorial introducing the PISA computer environment and two randomly chosen 20-minute units of tasks in digital reading, mathematics, or problem-solving. About 3/4 of the students received at least one digital reading cluster. A cluster comprised four so-called digital reading units. A unit is an item stimuli (i.e., a hypertext) including two to four reading items referring to that stem. The unit hypertext provided functional menus, tabs, buttons, and hyperlinks which could be used freely for transitions between nine to 33 nodes in total. The hypertexts covered different reading situations (e.g., public, educational, private) and text formats (e.g., continuous, non-continuous). Figure 3 gives an example of a digital reading unit. It shows the 12 nodes of the unit *Sports Club*. The unit introduces an email exchange between two girls looking for a gym (i.e., the start node). There are four hyperlinks given in the email exchange that open up the homepages of four gyms in new tabs. As soon as activated, students could freely move between the tabs. Two of the four gym websites provided additional sub-nodes that could be accessed through hyperlinks on the homepages.

In total, digital reading was assessed with 19 items, nested in six units and two clusters (OECD, 2013). Performance in digital reading is often assessed as the recall performance of text information or structures (e.g., Lee & Tedder, 2003; Pazzaglia et al., 2008), essay writings (e.g., Naumann et al., 2007, 2008), or selections of link titles (e.g., Pan et al., 2007; Rouet et al., 2012). Item response formats in the PISA digital reading units included multiple-choice selections, short open text answers, or mixed forms assessing text comprehension. The items were distinguished by particular cognitive operations. These operations – or reading aspects (OECD, 2013) – are not meant to be strictly hierarchical, but emphasize main aspects in dealing with information by extracting explicitly stated information (*access and retrieve*), inferring on implicitly stated information (*integrate and interpret*), evaluating information on the basis of one's own knowledge and experiences (*reflect and evaluate*), or combinations of these aspects (*complex*). The items of the *Sport Club* unit, for example, request students to find out at which day of the week the girls can go to a gym (*integrate and interpret*), to find out which one is the cheapest gym (*access and retrieve*), and to give a recommendation to the girls about which gym to join (*complex*). An example for a *reflect and evaluate* task is to ask readers to give their opinion on a VocabTrainer that was advertised within the text (unit *Language Learning*).

Measures of individual information selection in digital reading items were derived from process data that was collected during reading. Events of leaving a displayed node and entering another node were extracted from students' log records and counted as visits. Visits were classified according to their relationship to a given reading task. That is, nodes could contain information being necessary to solve a task appropriately (target nodes) as well as information being irrelevant to a task at all (irrelevant nodes). Accordingly, numbers of visits to target and irrelevant nodes were counted itemwise per student—either as unique visits or visits in total (i.e., including re-visits).

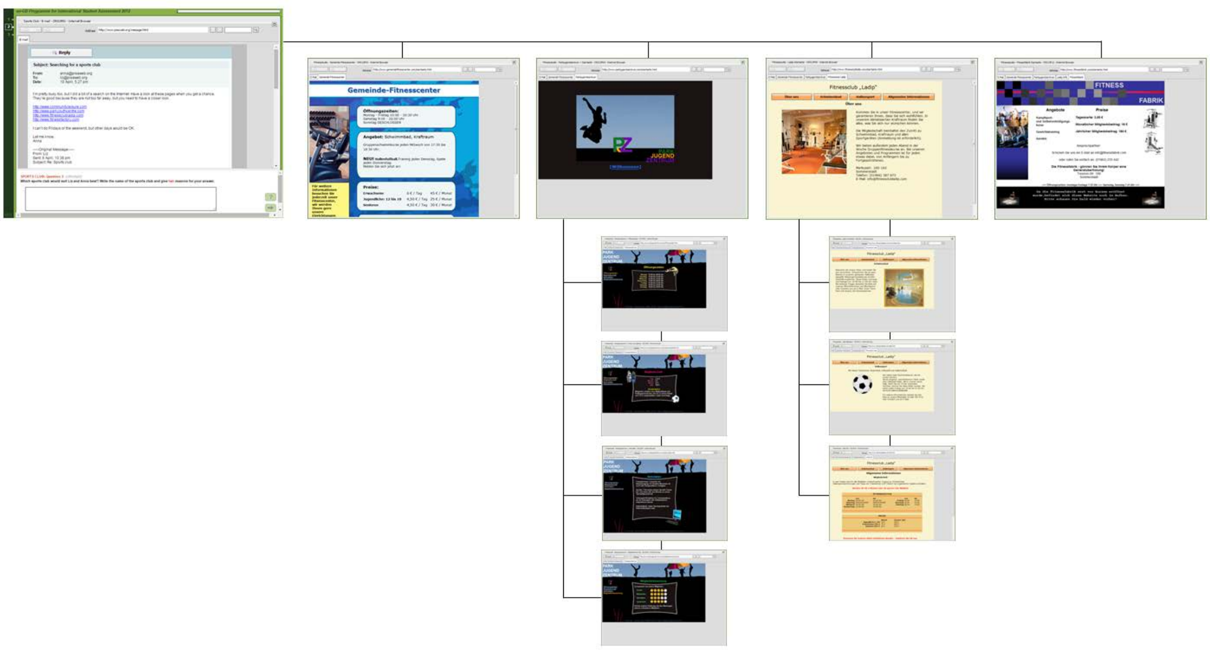

Figure 3. Structure of the Digital Reading Unit CR013 *Sports Club*.

In the context of the CBA add-on study, students were asked to participate in a series of tasks on an additional testing day (Figure 2). The tasks included assessments of linear reading using PISA reading tasks from 2009 (OECD, 2010), skills in working memory as well as in reading on the word and sentence level, and ICT skills. Linear reading was administered as computer-based or paper-based test. Each student received at least one of two linear reading clusters. Half of the students responded to the second reading cluster that was administered in the opposite administration mode. Linear reading was measured with a total of 29 items that—like in digital reading—included different reading situations, text formats, and cognitive aspects. About 3/4 of the students received a memory updating task to measure their skill in maintaining and updating contents in working memory (Oberauer & Kliegl, 2006). The 21 items of this test were administered together with two basic reading tests (Richter, Isberner, Naumann, & Kutzner, 2012) assessing students' word recognition (32 lexical decision tasks) and semantic integration skills (24 sentence verifications tasks). Two tests were used to measure ICT skills: the 20 items of the Basic Computer Skill Scale to assess students' skills in dealing with computer user interfaces (Goldhammer et al., 2013) and the 16 items of the Test for the Evaluation of Online Information (TEO; Goldhammer et al., 2013) to assess how students use surface and message cues for the selection of information. Especially, the TEO items can be considered to present special cases of digital reading since they provided a surface that simulates a search engine result page (SERP). TEO tasks request students to select the hyperlink that fits a given search task and that is taken from a credible source. In half of the items, students even had the option to visit the websites connected to the SERP hyperlinks (Figure 4).

Figure 4. Example of a TEO item on the risks of paragliding.

3.1 STUDY 1: Reading digital text involves working memory updating based on task characteristics and reader behavior

This study examined how demands in digital reading interact with working memory as a limited cognitive resource in individuals (Feldman Barrett et al., 2004). In general, working memory takes an essential part in reading. It enables readers to simultaneously process and integrate information retrieved from the text as well as activated from long-term memory (e.g., Daneman & Merikle, 1996; Just & Carpenter, 1992). Beside these demands, digital reading also requires the flexible and simultaneous monitoring and manipulation of semantic and spatial representations (cf. Coiro 2011; DeStefano & LeFevre, 2007; Foltz, 1996). Therefore, its relation to memory updating as domain-general skill to maintain and update temporary bindings in working memory (Wilhelm, Hildebrandt, & Oberauer, 2013; Oberauer, 2009) was specifically investigated over and above skills in reading linearly structured text. Based on the concept of cognitive load (Sweller et al., 2011), an effect of memory updating was expected to be affected by cognitive operations in reading tasks, characteristics of the hypertext structure, and individual reading behavior.

(1) Concerning cognitive operations in reading tasks, hypertext-specific demands should especially occur when a task requires readers to locate and find information in a hypertext at first. Therefore, it was hypothesized that the memory updating effect would be more pronounced in tasks requiring the extraction of information compared to tasks focusing on the expression of ideas and the use of knowledge. (2) Concerning the hypertext structure, it was argued that entering new nodes would require readers to set up bindings about the location, content and relations of nodes. As a consequence, they would need to evaluate and update their mental representation more often. This led to the hypothesis that the memory updating effect would increase with the number of nodes in a hypertext. (3) Finally, the memory updating effect was expected to be offset when readers would apply controlled adjustments to their reading (e.g., rereading; cf. Walczyk, 2000). As such an adjustment, revisiting nodes with highly relevant information was supposed to alleviate effects of individual differences in memory updating skills.

The data of 288 students (53.47% female, M_{age} = 15.85 years) was investigated. Examined variables included scores in digital reading, linear reading, and memory updating. On the task level, the numbers of relevant and irrelevant nodes in a hypertext as well as cognitive operations in reading tasks were regarded. As indicators of students' reading behavior, the numbers of unique visits and visits in total to target nodes and irrelevant nodes were derived. Generalized linear mixed models (DeBoeck & Wilson, 2004) were used to regress the dichotomized digital reading scores on several predictors on the student and item level while accounting for the hierarchical data structure.

Although linear reading already explained a large amount of variance in digital reading ($b = 0.59$, $p < .001$), the results showed a general effect of memory updating on digital reading ($b = 0.26$, $p < .001$). This suggested that students benefit from efficient working memory functions over and above their linear reading skills when reading digital text. The results correspond to relational pattern found in studies using other methodological approaches (e.g., Lee & Tedder, 2003; Naumann et al., 2008) supporting the general assumption that decisional and navigational demands in hypertext draw upon working memory resources. In interaction with item variables, the effect of memory updating vanished when students were instructed to evaluate text (drop of the regression coefficient by -.42, $p < .001$ in *reflect and evaluate* items) instead of extracting text information (estimation of $b = .39$, $p < .001$ in *access and retrieve* items; non-significant changes in items of other reading aspects). This led to the conclusion that memory updating skills serve the need to keep text bindings active while locating and evaluating further information in the digital space. The number of available nodes in a hypertext did not affect the memory updating effect (non-significant interaction effects of memory updating with the number of target and irrelevant nodes). In line with a study that disproved the number of hyperlinks on websites to be a source of cognitive load in digital reading (Madrid, Van Oostendorp, & Puerta Melguizo, 2009), it was concluded that the extent of a hypertext system does not influence per se individuals' representation of hypertext in working memory. Instead, readers' individual behavior determines how information is perceived and processed. Accordingly, the study results showed that the memory updating effect was accelerated by the number of target nodes students actually accessed (interaction effect of $b = .11$, $p = .015$). This interaction, though, was not retained when revisits to target nodes were counted in (non-significant interaction effect) as well as not reproducible with visits to irrelevant nodes. This suggested that students can apply strategies in dealing with hypertext environments to compensate for comprehension deficits. Hereby, revisits were assumed to reflect rereading activities. However, what exactly students did when revisiting a particular node was not traceable.

3.2 STUDY 2: Effects of linear reading, basic computer skills, evaluating online information, and navigation on reading digital text

The study spotlights the interplay of linear reading skills, ICT-related skills and navigation behavior in digital reading. Based on the dilemma that readers often need to locate information for a specific reading purpose in an unknown hyperspace (cf., Boechler & Dawson, 2005; Leu et al., 2004), linear reading skills as well as basic computer skills and evaluating online information as ICT-related skills were suggested as fundamental influences on digital reading mediated through task-relevant navigation. Task-relevant navigation was hereby defined as the act of selecting task-relevant nodes in a hypertext.

(1) Since linear reading skills should enable readers to extract the meaning of displayed nodes and to interpret semantic cues of hyperlinks, they were expected to support readers in identifying nodes with task-relevant contents. Consequently, readers' comprehension would be based on an appropriate text base (Lawless & Schrader, 2008; Rouet et al., 2011). Besides this mediation effect, linear reading skills were still expected to be predictive for digital reading since reading requires not only finding information, but include further processes of integrating information across nodes and understanding the context (Salmerón & García, 2011). (2) In case of basic computer skills, a complete mediation on digital reading through task-relevant navigation was proposed. Since they comprise fundamental skills in accessing, collecting and providing information with the aid of computers (Goldhammer et al., 2013), basic computer skills were expected to enable readers in the technical use of features of current computer interfaces (i.e., the hypertext) supporting their comprehension only indirectly (cf. Gall & Hannafin, 1994). (3) The second ICT-related skill—evaluating online information—was considered to reflect readers' skill in determining the usefulness of hypertext information. Since the flow of reading is usually not guided in hypertext, readers are required to make forward predictions about upcoming content and its relevance for a particular reading task (Coiro, Castek, & Guzniczak, 2011; Madrid et al., 2009). Therefore, evaluating skills were expectd to support readers in identifying relevant information and, therefore, to contribute to comprehension.

The mediation hypotheses were tested on a data basis of 888 students (48.4% female, M = 15.82 years). Students' scores in digital reading, linear reading, basic computer skills and evaluating online information were parceled according to an item-to-construct-balance approach (Little, Cunningham, Shahar, & Widaman, 2002). Students' navigation behavior was operationalized as the average of their task-relevant node selection across tasks. Using the technique of full information maximum likelihood (FIML; Enders & Bandalos, 2001), latent regression and mediation models were conducted (Kline, 2011; MacKinnon, 2008). Although the predictors of students' cognitive skills were highly correlated, the results confirmed unique and significant contributions of linear reading ($\hat{\beta}$ = .32, p < .001), basic computer skills ($\hat{\beta}$ = .31, p = .002), and evaluating online information ($\hat{\beta}$ = .26, p = .021) that explained 64% of the variability in digital reading. The number of relevant page visits was also strongly predictive of digital reading performance ($\hat{\beta}$ = .80, p < .001) showing that students who visited more task-relevant nodes received higher scores in digital reading. When taking the predictors together into the proposed mediation model, the variance explained in digital reading was even larger (R^2 = .81).

As expected, the effect of linear reading skills on digital reading was incompletely mediated through task-relevant navigation showing a medium indirect effect ($\hat{\beta}$ = .12, p = .013, κ = .15) and a remaining direct effect of linear reading ($\hat{\beta}$ = .20, p = .009). Hence, linear reading accounted for an observable behavior that was closely related to digital text comprehension. In line with previous research (Salmerón & García, 2011), the results stressed the interpretation that skilled readers engage with hypertext in a more task-oriented way than less skilled readers, resulting in intense task-relevant navigation and better comprehension of digital text. The influence of linear reading further went over and above the mere selection of information emphasizing other reading-related processes shared between linear reading and digital reading (e.g., integration of one's own knowledge; Salmerón et al., 2005).

Concerning basic computer skills, the results of the mediation analysis were also in line with the hypotheses. Students with well-developed basic computer skills visited more task-relevant pages and performed better in reading digital text, showing a medium indirect effect ($\hat{\beta}$ = .15, p = .003, κ = .19) and no remaining direct effect ($\hat{\beta}$ = .16, n.s.). Students with routinized computer skills were able to flexibly use and traverse digital environments enabling them to fluently locate and access task-relevant nodes and empowering their text comprehension indirectly. It was speculated whether efficient basic computer skills would rather release additional cognitive resources for students (cf. Naumann et al., 2008) or support students in constructing a cognitive map of the hypertext for orientation (cf. Rouet et al., 2012).

Students' skill in evaluating online information was directly predictive for digital reading ($\hat{\beta}$ = .20, p = .037) and not mediated through task-relevant navigation ($\hat{\beta}$ = .05, n.s.). Since evaluating online information comprises strategies of judging and predicting the relevance and credibility of presented online information, the direct effect stood in line with results of studies investigating the strategic use of previewing and skimming a page before deciding to act (e.g., Coiro & Dobler, 2007). It was speculated about the missing indirect effect that it might be due to the degree of guidance in digital reading task instructions or to relations with task-irrelevant rather than task-relevant navigation. Both guesses, though, had to be rejected. A third explanation was seen in a potential influence on time and effort in processing relevant and irrelevant information rather than navigation per se.

The same analyses were conducted with the number of nodes visited—another indicator of navigation that represents the comprehensiveness of reader's selection of relevant text rather than the intensity of readers' engagement with relevant material. The result pattern was identical with the previous analyses. In total, the study showed that well-developed reading and ICT-related skills are important prerequisites of digital reading by demonstrating unique proportions of variance explained through these components. Good readers with routinized skills in dealing with computers and effective strategies for deciding on the usefulness of web-based information are able to locate, evaluate, and synthesize web-based information.

3.3 STUDY 3: The role of reading for the evaluation of online information gathered from search engine environments

The study focuses on students' skill to evaluate online information in the context of web search. With the aid of search engines, web users can seek through the web for information. Over the course of this process, they formulate search queries and enter them into a search engine. As a result, search engine result pages (SERPs) list several text abstracts that are generally short, fragmented, and contain a hyperlink leading to a connected website (e.g., Gerjets, Kammerer, & Werner, 2011). The challenge for web users is to make a selection from this provided amount of information in a way that their selection will meet the requirements of a search task in terms of relevance and credibility (Brand-Gruwel et al., 2009). The quality and appropriateness of their evaluations, though, will depend on how web users receive and process information. Verbal SERP information is often just skimmed for keywords and phrases (e.g., Coiro & Dobler, 2007), but web users might also process SERP information rather systematically by comparing and weighing up the content of several hyperlink entries against each other. Therefore, it was assumed that reading skills on the word, sentence, and text level would support different ways of heuristic and systematic information processing (Wirth, Böcking, Karnowski, & von Pape, 2007), affecting students' evaluations of online information. These effects were expected to interact with semantic characteristics of SERP links and students' navigation behavior. Assuming that hyperlink selection is driven by the semantic similarity between presented information and a pursued search task (*information scent*; Blackmon, 2012) and that proficient readers process semantic information with lower mental effort than less skilled readers (Walczyk, 2000), the effects of reading skills were expected to increase, the more a SERP link stands out in relevance to a search task compared to other SERP links. With respect to students' navigation behavior determining the information base (cf. Rouet, 2006; Salmerón et al., 2005), reading skills were expected to interact with students' actions in navigating to a second SERP or, respectively, to websites connected to SERP hyperlinks.

Data of 416 15-year-old students (45.19% female, M_{age} = 15.84 years) were investigated. Using generalized linear mixed models (DeBoeck & Wilson, 2004), students' hyperlink selection from SERPs in TEO items were investigated as the dependent variable. On the person level, ability estimates for reading on the word, sentence, and text level served as independent variables. As item covariate, the indicator *variability in relevance* was determined as the variance of relevance ratings of the TEO hyperlinks (W_t = .69) from an independent rater sample (N = 7; 85.71% female; M_{age} = 29.43 years). Finally, dichotomous indicators of navigation behavior reflected whether or not students performed a page transition to a second SERP (4 items) or to SERP websites (8 items). They were used as person-by-item covariates.

The results showed that reading skills on the word, sentence, and text level predicted students' evaluations of online information positively. Accordingly, students will select appropriate information from SERPs when they are able to capture semantic contexts of fragmented texts. Yet, only semantic integration (b = .10, p = .028) and reading comprehension (b = .42, p <. 001) made an independent contribution. This confirms that the evaluation of online information involves different reading processes and indicates that they support different selection strategies (cf. Coiro & Dobler, 2007; Metzger, Flanagin, & Medders, 2010). The main effects of reading skills remained stable after adding interaction effects between reading skills and the variability in relevance of SERP links. The additional interaction effects showed an increase of the reading comprehension effect for an increasing variability in relevance of SERP hyperlinks (by .10, $p = .002$). This result suggests that skilled readers are at advantage in identifying semantic cues in hyperlinks. Therefore, it might be easier for them to determine the relevance of a hyperlink compared to less skilled readers (cf. Rouet et al., 2011). Consequently, skilled reader might turn away faster from irrelevant information saving their cognitive resources (cf. Walczyk, 2000).

Students' reading skills were further shown to interact with their navigation behavior. Half of the students did not show navigation behavior at all, but navigation was positively related to a higher skill in evaluating online information. In interaction with reading skills, there was an additional increase in the reading comprehension effect when students navigated to a second SERP (by .31, $p < .05$). The effects of reading on the word and sentence level remained unchanged in this case. A different pattern was found for students' navigation to websites of SERP hyperlinks. When students did not navigate, semantic integration and reading comprehension were not predictive for their hyperlink selection anymore, but there was still a main effect of word recognition ($b = .14$, $p < .05$). In contrast, reading comprehension changed to be predictive for the evaluation of online information when students visited websites (by .38, $p < .05$). The results indicate a mutual dependency between reading skills and navigation behavior. On the one hand, reading skills might trigger students to perform navigation. That could be the case when students cannot find information that fulfills predefined search criteria (e.g., relevance, credibility, cf. Blackmon, 2012; Rieh, 2002) or when they want to confirm or falsify their expectations about a link (cf. Coiro & Dobler, 2007). That would mean that navigation is the consequence of rather a thorough text elaboration or a comparison of SERP links, suggesting that experienced readers are in a better position to assess the need for additional information from websites than less skilled readers. On the other side, navigation brings up new text material that needs to be processed and evaluated in regard to its relevance. Since constituent skills of reading are more fluent in skilled readers (Walczyk, 2000), they process upcoming text information more efficiently with less mental effort. This might also mean that less skilled readers set other criteria that do not require navigation in order to prevent cognitive overload. Although the results cannot uncover specific strategies of information processing, they underline that students apply different strategies to evaluate online information and that specific reading skills can be supportive depending on the chosen strategy.

4. DISCUSSION AND CONCLUSIONS

Reading is the central process of comprehending written information and it is affected by various individual and situational influences (Groeben, 1982). This dissertation investigated influences that affect readers cognitively when they want to read text presented in a hypertext format. By reviewing characteristics of hypertexts in the beginning, four different categories of demands were distinguished that can produce cognitive load in readers working with digital text. Following the process model of learning with digital text proposed by Naumann (2012), these demands were used to derive hypotheses about what are important constituent cognitive skills of digital reading and how they will shape the digital reading process. In the following, it is shown how the main findings of the presented studies contribute to answer the research questions raised. Afterwards I reflect on the results' meaning and implications for the digital reading construct, outline important limitations of my work, and give directions for future research.

4.1 Digital Reading as a Complex Skill Composite

The first research questions focused on the identification of cognitive skills that constitute the digital reading process by enabling readers to meet demands of the text itself, its structure, the reading task and the computer environment in that hypertext is presented. The three studies showed that the comprehension of digital text of 15-year-olds is well explained by reading skills measured with linear text, working memory, evaluating online information, and basic computer skills. Reading comprehension was repeatedly found to be the most important, but not a perfect predictor of digital reading (study 1–3). Confirming a close relationship between linear reading and digital reading, this simultaneously indicated that only small effects of other cognitive skills could be expected. Such effects over and above linear reading were shown for the domain-general skill of memory updating (study 1) as well as ICT-specific components of evaluating online information and basic computer skills (study 2). Although these three skills were already highly positively correlated with linear reading, they made unique contributions in the explanation of students' digital reading performance. For evaluating web search results as special digital reading situation (study 3), there even were independent contributions of other reading processes—semantic integration and, under particular conditions, word recognition—than linear reading comprehension. This indicates strong influences of the chosen information processing strategies (Wirth et al., 2007) that could be supported differently through reading skills on the word, sentence, and text level.

The results strongly support the general assumption that reading digital text puts additional cognitive load on readers compared to reading linear text (e.g., Coiro, 2011; DeStefano & LeFevre, 2007; Leu et al., 2004; Rouet, 2009). Digital reading appears to be a composite skill of reading as well as general cognitive and ICT-specific skills. This also means that students showing deficits in their working memory, lacking basic computer skills, or having difficulties in evaluating online information are likely to have problems with understanding information from hypertext—in short, comprehension related problems will not be solely due to students' general reading skills. Cognitive demands in digital reading are manifold and differ from that required in linear reading. It cannot be concluded, though, that the effects of the constituent skills can be directly mapped onto the proposed categories of demands (i.e., concerning text, structure, task, and medium). As emphasized before, these categories are intertwined and only served to derive hypotheses about skills that compose the digital reading process. Specific to the reading situation, some demands will be more pronounced than others requiring different skills or skill sets. For example, if a reading task does not require students to form an adequate representation of the hypertext structure (i.e., interdependent task and structure related demands), resources of working memory might not be overly stressed. This was actually shown in study 1 where memory updating was only predictive for digital reading over and above linear reading skills when the task required the extraction of information from the hypertext (either explicitly or implicitly). Since the combined effect of working memory and ICT-specific skills was not investigated, one might also expect that resources of working memory get relieved if students can rely on well-routinized ICT skills providing them with heuristics, behavioral patterns, or schemata in dealing with digital environments.

The second research question followed the first one directly by asking how the identified connections of digital reading and its constituent skills can be explained in terms of information selection as observable navigation behavior. Readers' selection of information reflects how they interact with a text which determines the text base comprehension is based on. Hence, an appropriate information selection is essential for developing a comprehensive understanding. For digital reading, this assumption received confirmation in all my three studies as well as other research (e.g., Lawless & Kulikowich, 1996; Naumann et al., 2008; Salmerón et al., 2005) by showing high positive relations between students' navigation behavior and their digital text comprehension. It is important to note that the actual reader–text interaction demands for additional cognitive resources in readers rather than the mere number of hypertext nodes (study 1). Readers can even adapt their navigation behavior (e.g., re-visiting nodes with central information; study 1) to overcome restriction in their cognitive resources in a compensatory way, confirming the expected interaction of readers' working memory and their navigation behavior. Consequently, cognitive load in readers is not a linear function of the amount of presented information (Plass, 2005), but reader–text interactions and instructional signals (e.g., hyperlinks; cf. Naumann et al., 2007) have critical influences.

Study 2 demonstrated how information selection explained the relations of digital text comprehension with linear reading skills and the ICT-specific components (i.e., basic computer skills, evaluating online information). For linear reading, it was shown that skilled 15-year-old readers selected more task-relevant pages and comprehended digital text better than students lacking these skills. This mediation was incomplete, which is comparable to findings of Salmerón and García (2011) demonstrating an incomplete mediation of reading skills on hypertext learning through cohesive link selection in sixth graders. Cohesive link selection refers to a navigation behavior that is characterized by the selection of links that are semantically closely related to a previously read text part. Both studies suggest that skilled readers are better than poor readers at identifying and interpreting semantic cues in hyperlinks and embedding them into a task context. This interpretation gets additional support from study 3. Skilled readers were also able to select useful hyperlinks from a SERP although the hyperlink abstracts provided only fragmented text pieces. That was even more the case when the hyperlinks differed broadly in their relevance to a particular search task (i.e., the semantically close link alternative was easy to spot). Extending this relation, the results of study 3 further indicated a mutual relationship between reading skills and navigation behavior. The effect of reading skills (especially reading comprehension) on students' success in selecting task-relevant SERP links was moderated by their decisions to navigate to another SERP or website. On the one hand, skilled readers might seek information on other nodes only when needing more information to accomplish a particular reading task or when testing their hypotheses about upcoming content in a hypertext. In this case, semantic cues would help them making a decision which hyperlink to click on. On the other side, readers can expect that they will encounter further information through navigation. For skilled readers, it might indicate that they possess resources or skills to deal efficiently with the encountered amount of information (cf. Hamilton, Freed, & Long, 2013). According to this interpretation, missing navigation in poor readers would be a sign that they approach their cognitive limits of information processing and cope by avoiding new sources of information. Coming back to the mediation results of linear reading as predictor, it hints at why this mediation can only be incomplete. To a certain degree, readers will use their general knowledge to make more or less informed guesses about the relations of information in order to fill gaps in their digital text comprehension (e.g., Foltz, 1996; Rouet et al., 2011; Salmerón & Garcías, 2011).

With respect to the ICT-specific component skills, study 2 showed a complete mediation of basic computer skills on digital reading through readers' selection of information, demonstrating that well-routinized basic computer skills only account indirectly for comprehension by enabling students to access and flexibly re-access task-relevant nodes. Concerning the other ICT-related component skill, information selection did not explain the direct relationship between digital reading and the evaluation of online information. Hereby, study 2 ruled out effects of the degree of guidance in the instructions of the digital reading tasks as well as an explanation through irrelevant node visits. It also suggested that skilled evaluators might examine relevant information more intensively than irrelevant information, resulting in longer processing times.

All in all, the three studies demonstrated that digital reading is characterized through the interplay of a variety of cognitive skills (cf. Blatt, Kraska, Voss, & Goy, 2012; Naumann & Sälzer, in press; Rasmusson, 2015; Rasmusson & Eklund, 2013). Besides differences in linear reading, skilled digital readers showed advantages over less skilled readers in allocating their cognitive resources, evaluating upcoming information and dealing with functionalities of a given computer environment. Hence, digital reading is a reading activity that takes place in a complex environment. Yet, digital reading still seems ill-defined as a construct. According to the PISA terminology, digital reading comprises reading activities in a digital hypertext environment. The classification scheme of Table 1 (see section 1.1 Hypertext), though, would include linear text that is presented digitally as well. Hence, the definitions of digital reading and linear reading, which was measured with linear texts presented in print as well as digitally, would have a clear overlap. To a specific degree, linear text can be read in a non-linear way, and hypertext can be read in a linear fashion. For example, individuals might open websites as new tabs, but keep on reading on the last node instead of jumping to new sites. It cannot be clearly distinguished when and how often individuals actually perform digital reading instead of using a linearized reading strategy. A potential consequence might be to define digital reading in terms of reading strategies or reading tasks requiring navigation instead of grounding its definition on the text structure.

4.2 Digital Reading as a Contemporary Construct

As stated in the beginning (e.g., Kuhlen, 1991), hypertext as a way of organizing and relating information to each other was already known before technology made it possible to apply this structure to masses of information. Therefore, it is plausible—and in line with the three studies—that digital reading is a branch skill of reading ability that imposes additional demands concerning the level and the magnitude of information distribution. This means, though, that the PISA digital reading assessment co-measures other skills and is accordingly not applicable as a global instrument for reading diagnostics in students. Poor digital readers are not necessarily poor readers, but might fail to locate and access particular websites or predict upcoming content. This will result in a rather random selection of information and poor comprehension of digital text that cannot be attributed to impaired reading skills. Therefore, using the digital reading assessment for reading diagnostics might blur reading performance leading to biased conclusions about students' reading skills.

Yet, digital reading is a useful construct to describe a set of knowledge, skills, and abilities that are indispensable for adolescents in dealing with challenges of today's society. In this way, digital reading is a contemporary construct—a phenomenon of its time. Digital reading depends like any other ICT-related skills on the ICT context for which it is defined. Computer technologies have been developed with a tremendous speed within the last century. The private use of computer technologies and the WWW exists only since a few decades (e.g., Iske, 2002). While digital reading skills were not a topic a hundred years ago, they might not even be in the near future, assuming that the structure and the representation of information will develop into a new form. Although I focused particularly on computer representations in my studies, similar considerations probably apply in amended form for presentations on, for example, tablets, smartphones, or other portable devices.

New technologies serve and also generate individual and societal needs that require the proper handling of them (e.g., using the WWW for job search, tax paying, online shopping, social communication). For digital reading, the proper handling of hypertext structures and computer technologies were shown to depend on a broad range of different skills. The skilled use of digital text can be challenging for adolescents. It might be even more ambitious for young children who need to learn reading at first, but are simultaneously challenged with assessing the relevance of information, predicting upcoming section, and making navigational decisions in digital text. Although there is a heated public debate about the potential of computers to harm child development, children are growing up with technologies nowadays making it nearly impossible and inappropriate to seal them away from evolving technologies. Digital texts such as emails, blogs, and social networks play a dominant role in the daily life of adolescents (e.g., JIM study, Feierabend et al., 2016) and are increasing in popularity among children (e.g., KIM study, Feierabend, Karg, & Rathgeb, 2017). For this reason, it is important and meaningful to include digital reading as indicator in LSAs like PISA that aim at assessing students' preparedness for challenges of their adult life.

A special focus needs be set on instructing children and adolescents in how to deal with technologies in order to prevent their reading to be shallow. Schools are central institutions to enable and guide students to use digital information in a competent way (Iske, 2002). Some studies even demand fundamental changes of curricula to explicitly include trainings of skills in dealing with technologies (e.g., Felder, 2004; Larson, 2007; Leu et al., 2004; Thoermer & Williams, 2012). Nevertheless, Naumann and Sälzer (in press) argue that digital reading is likely to be mainly practiced outside school since only a small proportion of teachers in Germany put emphasis on teaching the efficient access and evaluation of online information (ICILS; Eickelmann, Schaumburg, Drossel, & Lorenz, 2014). In fact, digital technologies provide an inconceivable potential for individualized learning and instruction in terms of a broad diversity of learning opportunities that can be adapted to specific need of learners (see Garrison & Kanuka, 2004; Scheiter et al., 2009; Zumbach, 2010). For the acquisition and practice of digital reading skills, it means that the difficulty of reading tasks should be increased gradually to foster integration and evaluation skills in readers whereas corresponding hypertext should be designed in a way that fit current skill levels appropriately. However, an implementation will require thoroughly developed concepts of learning in digital classrooms, closely guided instructions for students as well as teachers, re-definitions of their roles in the learning process, and in particular the willingness to rethink traditional ways of instruction.

4.3 Limitations and Future Research Directions

There are several limitations that need to be regarded when interpreting the results of the studies presented. I want to concentrate on four main issues that are prominent for all the three studies. They concern the potential influences of not investigated reader characteristics, restrictions in the use and interpretation of data from log files, restrictions in simulation-based assessments, and the cross-sectional design and the correlative nature of the data. Although these limitations show restrictions in the knowledge gained, they also open up for future research to expand and deepen our knowledge about reading in the digital medium.

First, my work spotlights cognitive skills as precursors of successful digital reading. Yet, reading and learning are comprehensive processes that involve many more skills and attitudes of readers affecting how they plan their reading progress, monitor their comprehension, or decide when to stop reading (e.g., Ruttun & Macredie, 2012; Vidal-Abarca et al., 2010). Especially prior knowledge plays a major role in how easily readers are able to integrate information into representations of text and how they will interact with text (e.g., Amadieu, Tricot, & Mariné, 2009; Foltz, 1996; Möller & Müller-Kalthoff, 2000). By using their prior knowledge, knowledgeable readers can fill gaps in their comprehension and it comes easier to them to establish coherence between different text parts. This is also reflected in their navigation behavior that is more task-directed compared with low knowledge readers (Salmerón et al., 2005). As a side effect, they may not even experience the same amount of cognitive load resulting from hypertext and have cognitive resources available that they invest into comprehension or other controlled processes (cf. Madrid et al., 2009; Samuels & Flor, 1997). An important differentiation might be made between prior knowledge concerning the reading content and the medium in that text is presented. Being familiar with particular digital environments can enable students to compensate for deficient content knowledge up to a particular degree. Systematic comparisons of novices and expects could reveal better insights into that degree and also into strategy differences in dealing with digital text successfully.

Second, it is a special challenge to make cognitive processes visible along the progress of reading. In my studies, information selection was operationalized as counts of hypertext node visits or nodes visited, reflecting the intensity and comprehensiveness of node access. Indeed, indicators from log-file records can be seen as directly observable behavior, but the intention behind a page visit is not represented. There are several reasons for visiting a particular node, ranging from its semantic relatedness to previously read text to personal interests or demotivation (cf. Salmerón et al., 2010). Simultaneously, visit counts also abandon information about sequences and durations of node visits. Focusing on counts disambiguates and sharpens the interpretation of process indicators from log files, but it is accompanied with a loss of information that could have given insights into other facets of the digital reading process. The potential of process data analyses and especially of big data mining techniques seems not fully utilized yet in educational research on student competencies. There are promising attempts (e.g., math garden; Klinkenberg, Straatemeier, & van der Maas, 2011) that allow for personalized learning and monitoring of the learning progress based on continuous data collection and analyses. However, process data about how individuals learn, their current skills, and how they learn best is highly sensitive raising issues of data security and transparency that urgently need clarification.

Third, the generalizability of the presented results is restricted to closed and digital hypertext environments. These environments predefine the information that can be received and limit possible user actions to a specified set of actions. Accordingly, simulated hypertexts are comparably small and users cannot act completely naturally (e.g., define their own search terms for conducting web search). Although such simulation based assessments can only represent bits of reality and, therefore, cannot give universally valid information about processes in digital reading, the assessment approach allows focusing on micro processes of digital reading. Such micro-processes are hard to uncover under real-life conditions. For example, simulation based approaches restrict the material that participants can receive, making text amounts and their qualities comparable across individuals. Instead of comparing apples and oranges, specific behaviors and actions of readers under similar conditions and their interplay with individual characteristics can be isolated and investigated in detail to a certain degree. As similarly discussed above for the use and interpretation of process data, though, there are studies necessary that compare simulation based assessments with real-life assessments in order to cross-validate the interpretations we generate from derived performance measures. In this way, it will get clear how precisely performances in complex environments can be represented by the use of simulation based assessments.

Finally, the presented results are based on cross-sectional data. Although they allow for describing current skill levels and identifying skill patterns, correlational-based analyses cannot be used to go further in depicting causal relations or developments in the acquisition and progress of digital reading. At least, my studies show clearly that reading is the important skill to make use of written information and there are non-reading related challenges that readers need to face in the digital medium. Having the close relationship between linear and digital reading in mind, it raises issues about the preparedness and problems of young people for the demands of the digital society. Some studies already made an effort here by examining socio-demographical phenomena in digital reading that are already well-known in (linear) reading literacy research. For example, there was evidence of achievement gaps based on income and gender (e.g., Leu et al., 2014; Naumann & Sälzer, in press; Rasmusson & Åberg-Bengtsson, 2015). Besides demographical characteristics, the development of individual differences in reading skills is generally quite stable over time and there are scarcely any changes in the rank orderings between reader performances (Boland, 1993; Klicpera & Schabmann, 1993). However, there are concerns that the absolute performance difference in individuals' reading will widen in the course of students' schooling (i.e., Matthew effect; Stanovitch, 1986), but findings on that are quite heterogeneous (e.g., Bast & Reitsma, 1998). ICT-related skills might be a driving force that could widen an existing gap between good and poor readers. This Matthew effect would then result in strong disadvantages for less skilled digital readers. For now, my studies just hint at the influential extent of ICT-related cognitive skills and their limited compensational potential. Therefore, investigating their acquisition, development as well as developing relations of ICT skills and digital reading should take definitely part in future research.

References

Afflerbach, P., & Cho, B.-Y. (2008). Identifying and describing constructively responsive comprehension strategies in new and traditional forms of reading. In S. E. Israel & G. G. Duffy (Eds.), *Handbook of research on reading comprehension* (pp. 69–90). New York: Routledge.

Amadieu, F., Tricot, A., & Mariné, C. (2009). Prior knowledge in learning from a non-linear electronic document: Disorientation and coherence of the reading sequences. *Computers in Human Behavior*, *25*, 381–388.

Amadieu, F., van Gog, T., Paas, F., Tricot, A., & Mariné, C. (2009). Effects of prior knowledge and concept-map structure on disorientation, cognitive load, and learning. *Learning and Instruction*, *19*, 376–386.

Bast, J., & Reitsma, P. (1998). Analyzing the development of individual differences in terms of Matthew effects in reading: Results from a Dutch longitudinal study. *Developmental Psychology*, *34*, 1373-1399.

Blackmon, M. H. (2012). Information scent determines attention allocation and link selection among multiple information patches on a webpage. *Behaviour & Information Technology*, *31*, 3–15.

Blatt, I., Kraska, L., Voss, A., & Goy, M. (2012). Hypertexte verstehen: Studien mit Kindern aus Klasse 4. *Zeitschrift Für Grundschulforschung*, *5*, 89–100.

Boechler, P. M. (2001). How spatial is hyperspace? Interacting with hypertext documents: cognitive processes and concepts. *CyberPsychology & Behavior*, *4*, 23–46.

Boechler, P. M., & Dawson, M. R. W. (2005). The effects of spatial layout on relationships between performance, path patterns and mental representation in a hypermedia information search task. *Interactive Technology and Smart Education*, *2*, 31–46.

Boland, T. (1993). The importance of being literate: Reading development in primary school and its consequences for the school career in secondary education. *European Journal of Psychology of Education*, *8*, 289–305.

Bos, W., Eickelmann, B., & Gerick, J. (2014). Computer- und informationsbezogene Kompetenzen von Schülerinnen und Schülern der 8. Jahrgangsstufe in Deutschland im internationalen Vergleich. In W. Bos, B. Eickelmann, J. Gerick, F. Goldhammer, H. Schaumburg, K. Schwippert, … H. Wendt (Eds.), *ICILS 2013* (pp. 113–145). Münster: Waxmann.

Brand-Gruwel, S., Wopereis, I., & Walraven, A. (2009). A descriptive model of information problem solving while using internet. *Computers & Education*, *53*, 1207–1217.

Bürger, S., Kröhne, U., & Goldhammer, F. (2016). The transition to computer-based testing in large-scale assessments: Investigating (partial) measurement invariance between modes. *Psychological Test and Assessment Modeling*, *58*, 587–606.

Chen, S. Y., Fan, J.-P., & Macredie, R. D. (2006). Navigation in hypermedia learning systems: experts vs. novices. *Computers in Human Behavior*, *22*, 251–266.

Coiro, J. (2011). Predicting Reading Comprehension on the Internet: Contributions of Offline Reading Skills, Online Reading Skills, and Prior Knowledge. *Journal of Literacy Research : A Publication of the Literacy Research Association*, *43*, 352–392.

Coiro, Julie, Castek, J., & Guzniczak, E. (2011). Uncovering online reading comprehension processes: Two adolescents reading independently and collaboratively on the Internet. *Yearbook of the Literacy Research Association*, *60*, 354–369.

Coiro, Julie, & Dobler, E. (2007). Exploring the online reading comprehension strategies used by sixth-grade skilled readers to search for and locate information on the Internet. *Reading Research Quarterly*, *42*, 214–257.

Daneman, M., & Merikle, P. M. (1996). Working memory and language comprehension: A meta-analysis. *Psychonomic Bulletin & Review*, *3*, 422–433.

DeBoeck, P., & Wilson, M. (2004). *Explanatory Item Response Models: a Generalized Linear and Nonlinear Approach*. New York, NY: Springer New York.

DeStefano, D., & LeFevre, J.-A. (2007). Cognitive load in hypertext reading: A review. *Computers in Human Behavior*, *23*, 1616–1641.

Eickelmann, B., Schaumburg, H., Drossel, K., & Lorenz, R. (2014). Schulische Nutzung von neuen Technologien in Deutschland im internationalen Vergleich. In W. Bos, B. Eickelmann, J. Gerick, F. Goldhammer, H. Schaumburg, K. Schwippert, … H. Wendt (Eds.), *ICILS 2013* (pp. 197–230). Münster: Waxmann.

Enders, C. K., & Bandalos, D. L. (2001). The relative performance of full information maximum likelihood estimation for missing data in structural equation models. *Structural Equation Modeling*, *8*, 430–457.

Evans, J. S. B. T. (2008). Dual-Processing Accounts of Reasoning, Judgment, and Social Cognition. *Annual Review of Psychology*, *59*, 255–278.

Feierabend, S., Karg, U., & Rathgeb, T. (2013). *15 Jahre JIM-Studie. Studienreihe zum Medienumgang 12- bis 19-Jähriger 1998-2013*. Stuttgart: Medienpädagogischer Forschungsverbund Südwest.

Feierabend, S., Plankenhorn, T., & Rathgeb, T. (2016). *JIM-Studie 2016. Basisstudie zum Medienumgang 12- bis 19-Jähriger in Deutschland*. Stuttgart: Medienpädagogischer Forschungsverbund Südwest.

Feierabend, S., Plankenhorn, T., & Rathgeb, T. (2017). *KIM-Studie 2016. Basisstudie zum Medienumgang 6- bis 13-Jähriger in Deutschland*. Stuttgart: Medienpädagogischer Forschungsverbund Südwest.

Felder, E. (2004). Was ist textuell an Hypertexten? In M. Bönnighausen & H. Rösch (Eds.), *Intermedialität im Deutschunterricht* (pp. 40–62). Baltmannsweiler: Schneider Verlag Hohengehren.

Feldman Barrett, L., Tugade, M. M., & Engle, R. W. (2004). Individual Differences in Working Memory Capacity and Dual-Process Theories of the Mind. *Psychological Bulletin*, *130*, 553–573.

Foltz, P. (1996). Comprehension, Coherence, and Strategies in Hypertext and Linear Text. In Jean-Francois Rouet, J. J. Levonen, A. Dillon, & R. J. Spiro (Eds.), *Hypertext and Cognition* (pp. 109–136). Mahwah, NJ: Lawrence Erlbaum Associates.

Fraillon, J., Ainley, J., Schulz, W., Friedman, T., & Gebhardt, E. (Eds.). (2014). *Preparing for life in a digital age. The IEA International Computer and Information Literacy Study international report.* Cham: Springer.

Fu, W.-T., & Pirolli, P. (2007). SNIF-ACT: A cognitive model of user navigation on the World Wide Web. *Human Computer Interaction*, *22*, 355–412.

Gall, J., & Hannafin, M. (1994). A framework for the study of hypertext. *Instructional Science*, *22*, 207–232.

Garrison, D. R., & Kanuka, H. (2004). Blended learning: Uncovering its transformative potential in higher education. *The Internet and Higher Education*, *7*, 95–105.

Gerjets, P., Kammerer, Y., & Werner, B. (2011). Measuring spontaneous and instructed evaluation processes during Web search: Integrating concurrent thinking-aloud protocols and eye-tracking data. *Learning and Instruction*, *21*, 220–231.

Goldhammer, F., Keßel, Y., & Kröhne, U. (2013, April). *Construct validation of the ICT literacy scale TEO: Task characteristics and process measures*. Presented at the 5th Szeged Workshop on Educational Evaluation (SWEE), Szeged, Hungary.

Goldhammer, F., Naumann, J., & Keßel, Y. (2013). Assessing Individual Differences in Basic Computer Skills: Psychometric Characteristics of an Interactive Performance Measure. *European Journal of Psychological Assessment*, *29*, 263–275.

Groeben, N. (1982). *Leserpsychologie: Textverständnis - Textverständlichkeit*. Münster: Aschendorff.

Hamilton, S. T., Freed, E. M., & Long, D. L. (2013). Modeling Reader and Text Interactions During Narrative Comprehension: A Test of the Lexical Quality Hypothesis. *Discourse Processes*, *50*, 139–163.

Heine, J.-H., Sälzer, C., Borchert, L., Sibberns, H., & Mang, J. (2013). Technische Grundlagen des fünften internationalen Vergleichs. In M. Prenzel, C. Sälzer, E. Klieme, & O. Köller (Hrsg.), *PISA 2012. Fortschritte und Herausforderungen in Deutschland* (S. 309–343). Münster: Waxmann.

Hilligoss, B., & Rieh, S. Y. (2008). Developing a unifying framework of credibility assessment: Construct, heuristics, and interaction in context. *Information Processing & Management*, *44*, 1467–1484.

Horz, H., & Schnotz, W. (2008). Multimedia: How to combine language and visuals. *Language at work-Bridging theory and practice*, *4*, 43–50.

Iske, S. (2002). *Vernetztes Wissen: Hypertext-Strategien im Internet*. Bielefeld: Bertelsmann.

Johnson-Laird, P. N. (1980). Mental Models in Cognitive Science. *Cognitive Science*, *4*, 71–115.

Jonassen, D. H., & Wang, S. (1993). Acquiring Structural Knowledge from Semantically Structured Hypertext. *Journal of Computer-Based Instruction*, *20*, 1–8.

Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: individual differences in working memory. *Psychological Review*, *99*, 122.

Juvina, I., & van Oostendorp, H. (2008). Modeling Semantic and Structural Knowledge in Web Navigation. *Discourse Processes*, *45*, 346–364.

Kintsch, W. (1998). *Comprehension: A Paradigm for Cognition*. Cambridge University Press.

Klicpera, C., & Schabmann, A. (1993). Do German-speaking children have a chance to overcome reading and spelling difficulties? A longitudinal survey from the second until the eighth grade. *European Journal of Psychology of Education*, *8*, 307–323.

Klieme, E., Artelt, C., Hartig, J., Jude, N., Köller, O., Prenzel, M., … Stanat, P. (2010). *PISA 2009. Bilanz nach einem Jahrzehnt*. Münster: Waxmann.

Kline, R. B. (2011). *Principles and practice of structural equation modeling* (3rd ed). New York: Guilford Press.

Klinkenberg, S., Straatemeier, M., & van der Maas, H. L. J. (2011). Computer adaptive practice of Maths ability using a new item response model for on the fly ability and difficulty estimation. *Computers & Education*, *57*, 1813–1824.

Kröhne, U., & Martens, T. (2011). 11 Computer-based competence tests in the national educational panel study: The challenge of mode effects. *Zeitschrift Für Erziehungswissenschaft*, *14*, 169–186.

Kuhlen, R. (1991). *Hypertext : Ein nicht-lineares Medium zwischen Buch und Wissensbank [Hypertext: A non-linear medium between book and data base]*. Berlin: Springer.

Larson, L. C. (2007). Digital Readers: The next chapter in e-book reading and response. *The Reading Teacher*, *64*, 15–22.

Lawless, K. A., & Schrader, P. G. (2008). Where do we go now? Understanding research on navigation in complex digital environments. In D. J. Leu & J. Coiro (Eds.), *Handbook of New Literacies* (pp. 267–296). Hillsdale, NJ: Lawrence Erlbaum Associates.

Lawless, Kimberly A., & Kulikowich, J. M. (1996). Understanding Hypertext Navigation through Cluster Analysis. *Journal of Educational Computing Research*, *14*, 385–399.

Lazonder, A. W., & Rouet, J.-F. (2008). Information problem solving instruction: Some cognitive and metacognitive issues. *Computers in Human Behavior*, *24*, 753–765.

Lee, M. J., & Tedder, M. C. (2003). The effects of three different computer texts on readers' recall: based on working memory capacity. *Computers in Human Behavior*, *19*, 767–783.

Leong, C. K. (1992). Text-to-speech, text, and hypertext: Reading and spelling with the computer. *Reading and Writing*, *4*, 95–105.

Leu, Donald J., Forzani, E., Rhoads, C., Maykel, C., Kennedy, C., & Timbrell, N. (2014). The New Literacies of Online Research and Comprehension: Rethinking the Reading Achievement Gap. *Reading Research Quarterly*, *50*, 37–59.

Leu, Donald J., Kinzer, C. K., Coiro, J. L., & Cammack, D. W. (2004). Toward a Theory of New Literacies Emerging From the Internet and Other Information and Communication Technologies. In R. B. Ruddell & N. Unrau (Eds.), *Theoretical Models and Processes of Reading* (5th ed., pp. 1568 – 1611). Newark: International Reading Association.

Little, T. D., Cunningham, W. A., Shahar, G., & Widaman, K. F. (2002). To parcel or not to parcel: Exploring the question, weighing the merits. *Structural Equation Modeling*, *9*, 151–173.

MacKinnon, D. (2008). *Introduction to Statistical Mediation Analysis*. Mahwah, NJ: Erlbaum.

Madrid, R. I., Van Oostendorp, H., & Puerta Melguizo, M. C. (2009). The effects of the number of links and navigation support on cognitive load and learning with hypertext: The mediating role of reading order. *Computers in Human Behavior*, *25*, 66–75.

McDonald, S., & Stevenson, R. J. (1998). Effects of text structure and prior knowledge of the learner on navigation in hypertext. *Human Factors*, *40*, 18–27.

Metzger, M. J., Flanagin, A. J., & Medders, R. B. (2010). Social and Heuristic Approaches to Credibility Evaluation Online. *Journal of Communication*, *60*, 413–439.

Möller, J., & Müller-Kalthoff, T. (2000). Lernen mit Hypertext: Effekte von Navigationshilfen und Vorwissen: Learning with Hypertext: The Impact of Navigational Aids and Prior Knowledge. *Zeitschrift für Pädagogische Psychologie*, *14*, 116–123.

Müller-Kalthoff, T., & Möller, J. (2005). Zum Effekt unterschiedlicher Navigationshilfen beim Lernen mit Hypertexten: The Effects of Different Graphical Overviews on Hypertext Learning Achievement. *Zeitschrift für Pädagogische Psychologie*, *19*, 49–60.

Naumann, J. (2012). *Belastungen und Ressources beim Lernen aus Text und Hypertest [Demands and resources in learning from text and hypertext]* (Unveröffentlichte Habilitationsschrift). Goethe Universität, Frankfurt am Main.

Naumann, J., Richter, T., Christmann, U., & Groeben, N. (2008). Working memory capacity and reading skill moderate the effectiveness of strategy training in learning from hypertext. *Learning and Individual Differences*, *18*, 197–213.

Naumann, J., Richter, T., Flender, J., Christmann, U., & Groeben, N. (2007). Signaling in expository hypertexts compensates for deficits in reading skill. *Journal of Educational Psychology*, *99*, 791.

Naumann, J., & Salmerón, L. (2016). Does navigation always predict performance? Effects of navigation on digital reading are moderated by comprehension skills. *The International Review of Research in Open and Distributed Learning*, *17*. Retrieved from http://www.irrodl.org/index.php/irrodl/article/view/2113

Naumann, J., & Sälzer, C. (in press). Digital reading proficiency in German 15-year olds: Evidence from PISA 2012. *Zeitschrift Für Erziehungswissenschaft*. Retrieved from https://www.uni-frankfurt.de/62828257/Naumann_Saelzer_ZfE_in_press.pdf

Oberauer, K. (2009). Design for a Working Memory. *Psychology of Learning and Motivation*, *51*, 45–100.

Oberauer, K., & Kliegl, R. (2006). A formal model of capacity limits in working memory. *Journal of Memory and Language*, *55*, 601–626.

Organisation for Economic Co-operation and Development (OECD). (2010). *PISA 2009 Assessment Framework*. Paris: Organisation for Economic Co-operation and Development.

Organisation for Economic Co-operation and Development (OECD). (2011). *PISA 2009 Results: Students On Line*. OECD Publishing.

Organisation for Economic Co-operation and Development (OECD). (2013). *PISA 2012 Assessment and Analytical Framework*. OECD Publishing.

Organisation for Economic Co-operation and Development (OECD). (2014). *PISA 2012 Technical Report*. OECD Publishing.

Pan, B., Hembrooke, H., Joachims, T., Lorigo, L., Gay, G., & Granka, L. (2007). In Google We Trust: Users' Decisions on Rank, Position, and Relevance. *Journal of Computer-Mediated Communication*, *12*, 801–823.

Pazzaglia, F., Toso, C., & Cacciamani, S. (2008). The specific involvement of verbal and visuospatial working memory in hypermedia learning. *British Journal of Educational Technology*, *39*, 110–124.

Perfetti, C. (2007). Reading Ability: Lexical Quality to Comprehension. *Scientific Studies of Reading*, *11*, 357–383.

Perfetti, C., & Stafura, J. (2014). Word Knowledge in a Theory of Reading Comprehension. *Scientific Studies of Reading*, *18*, 22–37.

Plass, J. L. (2005). Aktuelle Trends in der Forschung zu Hypertext- und Hypermediasystemen. *Zeitschrift für Pädagogische Psychologie*, *19*, 77–83.

Rammstedt, B., Ackermann, D., GESIS - Leibniz-Institut für Sozialwissenschaften, & Deutschland (Eds.). (2013). *Grundlegende Kompetenzen Erwachsener im internationalen Vergleich: Ergebnisse von PIAAC 2012*. Münster: Waxmann.

Rasmusson, M. (2015). Reading Paper–Reading Screen-A Comparison of Reading Literacy in Two Different Modes. *Nordic Studies in Education*, *34*, 3–19.

Rasmusson, M., & Åberg-Bengtsson, L. (2015). Does Performance in Digital Reading Relate to Computer Game Playing? A Study of Factor Structure and Gender Patterns in 15-Year-Olds' Reading Literacy Performance. *Scandinavian Journal of Educational Research*, *59*, 691–709.

Rasmusson, M., & Eklund, M. (2013). "It's easier to read on the Internet—you just click on what you want to read…": Abilities and skills needed for reading on the Internet. *Education and Information Technologies*, *18*, 401–419.

Richter, T., Isberner, M.-B., Naumann, J., & Kutzner, Y. (2012). Prozessbezogene Diagnostik von Lesefähigkeiten bei Grundschulkindern [Process-oriented Assessment of Reading Skills in Primary School Children]. *Zeitschrift Für Pädagogische Psychologie*, *26*, 313–331.

Rieh, S. Y. (2002). Judgment of information quality and cognitive authority in the Web. *Journal of the American Society for Information Science and Technology*, *53*, 145–161.

Rouet, Jean-François. (2006). *The skills of document use: from text comprehension to Web-based learning*. Mahwah, NJ: Erlbaum.

Rouet, Jean-François. (2009). Managing cognitive load during document-based learning. *Learning and Instruction*, *19*, 445–450.

Rouet, Jean-François, & Levonen, J. J. (1996). Studying and Learning with Hypertext: Empirical Studies and Their Implications. In Jean-François Rouet, J. J. Levonen, A. Dillon, & R. J. Spiro (Eds.), *Hypertext and Cognition* (pp. 9–24). Mahwah, NJ: Lawrence Erlbaum Associates.

Rouet, Jean-Francois, Levonen, J. J., Dillon, A., & Spiro, R. J. (1996). An Introduction to Hypertext and Cognition. In Jean-François Rouet, J. J. Levonen, A. Dillon, & R. J. Spiro (Eds.), *Hypertext and Cognition* (pp. 3–8). Mahwah, NJ: Lawrence Erlbaum Associates.

Rouet, Jean-François, Ros, C., Goumi, A., Macedo-Rouet, M., & Dinet, J. (2011). The influence of surface and deep cues on primary and secondary school students' assessment of relevance in Web menus. *Learning and Instruction*, *21*, 205–219.

Rouet, Jean-François, Vörös, Z., & Pléh, C. (2012). Incidental learning of links during navigation: the role of visuo-spatial capacity. *Behaviour & Information Technology*, *31*, 71–81.

Ruttun, R. D., & Macredie, R. D. (2012). The effects of individual differences and visual instructional aids on disorientation, learning performance and attitudes in a Hypermedia Learning System. *Computers in Human Behavior*, *28*, 2182–2198.

Salmerón, L., Kintsch, W., & Kintsch, E. (2010). Self-regulation and link selection in hypertext. *Discourse Processes*, *47*, 175–211.

Salmerón, Ladislao, Cañas, J. J., Kintsch, W., & Fajardo, I. (2005). Reading Strategies and Hypertext Comprehension. *Discourse Processes*, *40*, 171–191.

Salmerón, Ladislao, & García, V. (2011). Reading skills and children's navigation strategies in hypertext. *Computers in Human Behavior*, *27*, 1143–1151.

Samuels, S. J., & Flor, R. F. (1997). The importance of automaticity for developing expertise in reading. *Reading & Writing Quarterly*, *13*, 107–121.

Scheiter, K., Gerjets, P., Vollmann, B., & Catrambone, R. (2009). The impact of learner characteristics on information utilization strategies, cognitive load experienced, and performance in hypermedia learning. *Learning and Instruction*, *19*, 387–401.

Schnotz, W., Ludewig, U., Ullrich, M., Horz, H., McElvany, N., & Baumert, J. (2014). Strategy shifts during learning from texts and pictures. *Journal of Educational Psychology*, *106*, 974–989.

Scott, B. M., & Schwartz, N. H. (2007). Navigational spatial displays: The role of metacognition as cognitive load. *Learning and Instruction*, *17*, 89–105.

Stanovich, K. E. (1986). Matthew effects in reading: Some consequences of individual differences in the acquisition of literacy. *Reading Research Quarterly*, 360–407.

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

Thoermer, A., & Williams, L. (2012). Using digital texts to promote fluent reading. *The Reading Teacher*, *65*, 441–445.

Vidal-Abarca, E., Mañá, A., & Gil, L. (2010). Individual differences for self-regulating task-oriented reading activities. *Journal of Educational Psychology*, *102*, 817–826.

Walczyk, J. J. (2000). The interplay between automatic and control processes in reading. *Reading Research Quarterly*, *35*, 554–566.

Wenger, M. J., & Payne, D. G. (1996). Comprehension and Retention of Nonlinear Text: Considerations of Working Memory and Material-Appropriate Processing. *The American Journal of Psychology*, *109*, 93–130.

Wilhelm, O., Hildebrandt, A., & Oberauer, K. (2013). What is working memory capacity, and how can we measure it? *Frontiers in Psychology*, *4*.

Wirth, W., Böcking, T., Karnowski, V., & von Pape, T. (2007). Heuristic and Systematic Use of Search Engines. *Journal of Computer-Mediated Communication*, *12*, 778–800.

Zumbach, Joerg, & Mohraz, M. (2008). Cognitive load in hypermedia reading comprehension: Influence of text type and linearity. *Computers in Human Behavior*, *24*, 875–887.

Zumbach, Jörg. (2010). *Lernen mit neuen Medien [Learning with new media]* (1. Aufl). Stuttgart: Kohlhammer.

STUDY 1

Publication Note

Hahnel, C., Goldhammer, F., Kröhne, U., & Naumann, J. (under review, *Learning and Individual Differences*). Reading digital text involves working memory updating based on task characteristics and reader behavior.

Reading digital text involves working memory updating based on task characteristics and reader behavior

Receiving and using web-based information has become part of everyday life, but the non-linear presentation of information can make considerable demands on cognitive resources, affecting text comprehension. This study examined whether memory updating predicts students' comprehension of digital hypertext over and above skills in reading linearly structured text, and whether this association is affected by particular characteristics of reading tasks, the hypertext and individual reading behavior. Measures included reading comprehension as assessed via hypertext (digital reading) and linear text (linear reading) as well as memory updating among 15-year-old German students (N = 288). The number of nodes in a hypertext and cognitive reading operations required for task processing were regarded as task characteristics. Indicators of reader behavior were derived from log files. The results demonstrated a general effect of memory updating on digital reading over and above linear reading. This effect was not affected by the number of available nodes but by cognitive reading operations and individual reader behavior. Implications for students' cognitive processing of hypertexts are discussed.

In today's society, receiving and using information from the World Wide Web (WWW) has become integral part of many private, academic, and occupational activities (Leu, Kinzer, Coiro & Cammack, 2004). As a result, measures of reading web-based information have been included in international comparative studies like the Programme for International Student Assessment (PISA), which aims to evaluate the skills and knowledge of students at the end of compulsory education (OECD, 2011). Web-based information is frequently structured in the form of non-linearly organized text pieces ("nodes") that are associated with one another and accessible through hyperlinks. Hypertexts offer readers numerous ways of collecting and combining pieces of information for specific reading purposes. However, processing information that is not presented contiguously can seriously affect comprehension of a text (Coiro, 2011; Rouet, 2006), since individuals' cognitive resources are limited (Feldman Barrett, Tugade & Engle, 2004) and decision-making and navigation requirements add to the load on readers' working memory (WM; DeStefano & LeFevre, 2007; Foltz, 1996; Scheiter, Gerjets, Vollmann & Catrambone, 2009).

In the present study, we investigated interindividual differences in 15-year-old German PISA students' comprehension of hypertexts. We examined how such differences are related to memory updating – the individual skill of actively monitoring and manipulating WM content (e.g., Oberauer & Kliegl, 2006). We aimed to investigate (1) whether memory updating is predictive of students' hypertext comprehension over and above their general reading skills, and (2) whether such an association is affected by particular characteristics of reading tasks, the hypertext and reading behavior. Examining these research questions will provide evidence on the relation between hypertext comprehension and WM (e.g., Naumann, Richter, Christmann & Groeben, 2008; Pazzaglia, Toso & Cacciamani, 2008), and generate further insights on the nature of information processing from hypertext. In the following, we will refer to the skills of comprehending electronic hypertext and linearly structured text as digital reading and linear reading, respectively.

1.1 Working memory and digital reading

Reading is an individual process of receiving and processing written information, ranging from decoding and recognizing words up to higher processes of word-text integration and meaning making (Perfetti & Stafura, 2014). In both digital and linear text, information should be conveyed in a coherent form that enables readers to extract meaning and to form a mental representation of the text situation (Foltz, 1996; Kintsch, 1998). In this regard, WM generally plays an essential role since individuals need to integrate information retrieved from the text and information activated from their long-term memory (e.g., Daneman & Merikle, 1996; Hannon, 2012; Oakhill, Yuill & Garnham, 2011). Hypertexts, though, offer readers a great deal of freedom in terms of how they receive information by simultaneously providing fewer cues about what information to process next and where to find it (Foltz, 1996). Therefore, digital reading requires increased activation of cognitive resources to allow readers to deal appropriately with the non-linear text structure without getting lost (Coiro 2011; Gyselinck, Jamet & Dubois, 2008; Srivastava & Gray, 2012). Accordingly, visuospatial WM capacity was shown to be associated with the recognition of hypertext structures among sixth graders, whereas verbal recall predicted their semantic knowledge (Pazzaglia et al., 2008). These effects were not due to linear reading skills, prior knowledge or short term memory. Similar effects were found for university students. Readers with a low verbal WM capacity recalled noticeably less information from digital text than from linear text (Lee & Tedder, 2003), and low visuospatial WM capacity was associated with difficulties in recalling hypertext structures and keeping track of link hierarchies (Rouet, Vörös & Pléh, 2012).

Previous studies have mainly related digital reading processes to verbal and visuospatial WM subcomponents, but not to the domain-general WM functions of active information storage and processing. Conceptualizing WM as "a system for building, maintaining and rapidly updating arbitrary bindings" for goal-directed information processing (Wilhelm, Hildebrandt & Oberauer, 2013, p.3), the memory updating paradigm was found to be a good representation of the individual skill to flexibly bind structures into mental WM representations (Schmiedek, Hildebrandt, Lövdén, Wilhelm & Lindenberger, 2009). In contrast to other WM theories (e.g., Engle, 2002; Miyake et al., 2000), WM capacity limits are assumed to arise from interference due to temporary bindings that limit the complexity of novel representations (Oberauer, 2009). Since digital reading requires making sense of text by simultaneously monitoring and flexibly manipulating representations of the text situation and spatial relations between nodes, it should be closely related to memory updating.

1.2 Task influences

In general, readers are sensitive to demands of reading tasks that influence the way of their cognitive information processing (cf. Kendeou, van den Broek, Helder & Karlsson, 2014; Naumann, 2015; McCrudden & Schraw, 2007; Rouet, 2006). Such demands are often described as sources of cognitive load in WM (DeStefano & LeFevre, 2007; Rouet, 2009; Scheiter et al., 2009). Higher cognitive load is associated with differences in learning performance across different text structures (Zumbach & Mohraz, 2008), navigational maps (Amadieu et al., 2009; Scott & Schwartz, 2007), and reading orders (Madrid, Van Oostendorp & Puerta Melguizo, 2009). Readers reported less cognitive load, for example, when they had high prior knowledge or positive attitudes towards the text content (Amadieu, van Gog, Paas, Tricot & Mariné, 2009; Scheiter et al., 2009).

In PISA (OECD, 2013, p.66), "mental strategies, approaches or purposes that readers use to negotiate their way into, around and between texts" are described as "reading aspects". These include the facets *access and retrieve*, *integrate and interpret*, *reflect and evaluate* and – the digital reading-specific aspect – *complex*. Table 1 lists examples of each reading aspect as well as operations required for task processing. Illustrated tasks refer either to a hypertext detailing an email exchange between two girls looking for a sports club ("Sports Club"), or a social media-like language learning platform ("Language Learning"). The different methods of text processing invoked by these reading aspects (Table 1) might involve WM representations being updated differently. When asked for explicit or implicit text information (i.e., *access and retrieve*, *integrate and interpret*), students have to interact with the hypertext in order to locate and connect information distributed over a hypertext. As a result, they will put effort into decisional and navigational actions when searching the hypertext for the requested information. Keeping text information active and updated while using representations of spatial relations for navigating might then especially draw upon memory updating skills. In contrast, when asked to articulate an opinion (i.e., *reflect and evaluate*), students will have to retrieve ideas, attitudes, and experiences with similar texts from their general knowledge in a similar way to demands in linear reading.

Another task-specific influence might concern structural conditions in hypertexts. In their review of hypertext reading, DeStefano and LeFevre (2007) proposed that an increasing amount of information in hypertext – or more precisely, the number of hyperlinks – increases cognitive load in readers. Although there is some evidence against this claim (Madrid et al., 2009), it can be argued that memory updating might become especially important when required information is widely distributed across the text. Since readers need to create bindings regarding the location, content and relations of nodes, they might have to evaluate and update their mental representation of a hypertext every time a new node is encountered. This should hold for the nodes that are necessary and germane for a specific task (target nodes; cf. McCrudden & Schraw, 2007), but also for the nodes that are completely irrelevant to it (irrelevant nodes).

The way in that readers interact with a hypertext structure (i.e., their navigation behavior) particularly influences how text is received, processed and comprehended (e.g., Hahnel, Goldhammer, Naumann & Kröhne, 2016; Madrid et al., 2009; Naumann & Salmerón, 2015). Navigation requires more controlled processing since readers need to simultaneously integrate information as well as anticipate and plan their reading progress as they read (Foltz, 1996; Naumann & Goldhammer, 2017). Therefore, navigation events as recorded in log files, for example, are frequently used to shine a light on students' decisions and strategies of information access and use (cf. Scheiter et al., 2009). Empirically, navigation behavior has been found to partially mediate the effect of WM

Table 1

Examples of reading aspects in the digital reading items

Reading aspect	Description	Number of items	Instruction of an example task	Goal process in task example
Access and retrieve	finding, extracting and combining one or more pieces of information explicitly stated in the text	6	Unit *Sports Club*: Which sports club offers the cheapest monthly rates for 15-year-olds?	searching four websites to identify a match with a single specified criterion
Integrate and interpret	inferring on the basis of implicit assumptions, relations, or implications within the text to show a holistic understanding of the text	7	Unit *Language Learning*: What kind of service does language-learning.com provide for learners?	making inferences from text information on the function of a website
Reflect and evaluate	drawing upon one’s own knowledge and experiences, and relating them to text content and form	3	Unit *Language Learning*: Look at "My Messages". Do you think Rafael should take up the VocabTrainer suggestion? Write Yes or No and give a reason for your answer.	evaluating the credibility and utility of an advertisement through the use of contextual information
Complex	providing reading tasks that are as realistic as possible (i.e. encompassing features of all the former aspects)	3	Unit *Sports Club*: Which sports club would suit Liz and Anna best? Write the name of the sports club and give two reasons for your answer.	(1) locating descriptions in several websites by following a series of links, (2) comparing a series of descriptions with a set of requirements retrievable from the e-mail exchange, (3) integrating information from several websites and forming an opinion consistent with the requirements stated in the e-mail exchange

Note. Note that these reading aspects are not intended to be mutually exclusive but emphasize particular ways of text processing. Information about the items is derived from the PISA coding guidelines.

capacity on hypertext learning outcomes (Naumann et al., 2008), especially when it is characterized as the comparison of information from different perspectives (Kornmann et al., 2016). However, general reading skills have rarely been taken into account in previous studies. Less skilled readers might struggle to accurately choose relevant text sections or misjudge their level of comprehension (cf. Foltz, 1996; Salmerón, Cañas, Kintsch & Fajardo, 2005). According to Walczyk (2000), readers can apply controlled adjustments to their reading (e.g. rereading the text) in order to overcome deficits in decoding skills. Less skilled comprehenders, though, often believe they are able to answer questions without rereading text passages, decide more often against going back to a text and fail more often to give correct answers than skilled comprehenders (Vidal-Abarca, Mañá & Gil, 2010).

1.3 Rationale

In this study, we examined whether and how interindividual differences in memory updating as the individual skill to flexibly bind and unbind WM structures affect 15-year-olds' digital text comprehension. Memory updating is supposed to play a central role in simultaneously monitoring and manipulating representations of text and space and, therefore, should predict digital reading over and above joint processes with linear reading.

H1. The probability of solving a digital reading task correctly is predicted positively by both linear reading and memory updating.

Assuming that an impact of memory updating does not result from individual differences rooted in shared processes of digital and linear reading (e.g., decoding or comprehension processes), its effect on digital reading is expected to differ depending on specific reading conditions concerning cognitive operations and hypertext structure.

H2. The effect of memory updating is more pronounced in tasks focusing on the text base (i.e., access and retrieve, integrate and interpret) than in tasks requiring knowledge-based judgments (i.e., reflect and evaluate).

H3a. The memory updating effect increases with the number of target nodes.
H3b. The memory updating effect increases with the number of irrelevant nodes.

When readers encounter new target nodes, they need to form bindings related to the new information and update existing mental representations. However, in order to consolidate relevant WM content, readers might adjust their reading by revisiting target information. A "refreshing" of WM bindings could alleviate differences due to individual memory updating skills and help prevent deficits in comprehension.

H4a. The effect of memory updating increases with the number of target nodes visited.
H4b. The effect of memory updating is reduced when students revisit target nodes.

Method

2.1 Sample

Data from 288 15-year-old students (*M* = 15.85, *SD* = 0.29) was used (53.47% female). These students participated in the PISA 2012 digital reading assessment and additionally in a German add-on study on computer-based assessment (CBA). The PISA sampling procedure included a two-stage sampling design. Across 212 PISA-eligible schools, 14 students were randomly drawn to participate in PISA CBA (OECD, 2014), which included the digital reading assessment. Another 14 students from 77 schools were drawn to participate in the add-on study. The intersection of these two subsamples formed the data basis.

2.2 Materials and measures

2.2.1 Digital reading

Digital reading was assessed via 19 items, clustered into six units (OECD, 2013). A unit provided a simulated hypertext and included two to four reading items (Figure 1). The hypertext environment provided functional menus, tabs, buttons, and hyperlinks which students could use to navigate freely within the hypertext while answering a particular item. Navigation back to previous items was not possible. The hypertext content covered different reading situations (e.g., private, educational), text types (e.g., description, argumentation), and comprised between nine and 33 nodes in total. The number of target nodes (i.e., nodes with information required to solve a digital reading task correctly) ranged from one to five pages per item (*M* = 1.63, *SD* = 1.26). The fourth example task in Table 1, for instance, contained five target nodes: The email exchange that provided criteria on which students should base their answer (i.e., common date, sport preferences, low price) and the nodes of two gyms addressing these restrictions (one node for gym 1 and three for gym 2). Nodes that needed to be passed to reach a target node but did not contribute to task completion were considered neither target nor irrelevant. The number of irrelevant nodes (i.e., nodes which provide no helpful information for the task solution) ranged from four to 32 pages (M = 16.11, SD = 8.08).

Item response formats included multiple-choice questions, open text answers, and mixed formats. Open text responses were scored by trained coders with the aid of standardized coding guidelines (OECD, 2014). Students' responses were coded dichotomously. Six partial credit items were dichotomized to apply generalized linear mixed modeling (partial and full credit combined). Across items, the proportion of correct responses ranged from 17.84% to 94.47%. The items fit a Rasch model (Embretson & Reise, 2000) and appropriately covered the range of students' digital reading skills (Figure 2). Items for the reading aspect *access and retrieve* tended to be easier on average than items associated with other reading aspects, with *complex* items the most difficult. Cronbach's α (.77) and the reliability of expected a posteriori (EAP) scores (.74) were acceptable.

The reading aspects and the numbers of target and irrelevant nodes were regarded as task characteristics. To represent reader behavior, events recording visits to target nodes were extracted from students' log files. By averaging their visits across items, the number of target nodes *visited* (M = 1.55; SD = 0.45) and the number of target node *visits*

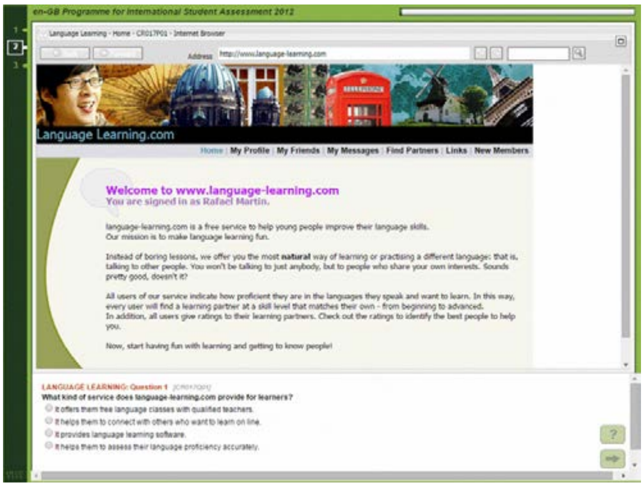

Figure 1. Screenshot of the digital reading hypertext "Language learning". Further example tasks can be retrieved from the PISA 2012 Assessment Framework (OECD, 2013, p.72-78) as well as from the OECD website (Annex A2, p. 233-247). https://www.oecd.org/pisa/pisaproducts/PISA%202009%20reading%20test%20items.pdf

(M = 2.68; SD = 1.17) were derived for each student. Note that the first indicator counts visits only once whereas the second indicator counts visits and revisits. To examine the specificity of the effects of goal-relevant navigation, similar indicators were also derived for irrelevant node visits (number of irrelevant nodes visited: M = 0.74, SD = 0.54; number of irrelevant node visits: M = 1.09, SD = 1.03).

2.2.2 Memory updating

Students were asked to complete a numerical memory updating task by memorizing a sequence of numbers and mentally adding or subtracting numbers presented afterwards. Figure 3 illustrates the process for one item. The start sequence varied from two to four digits. The operators ranged from -8 to +8. All start, interim, and resulting numbers ranged from zero to nine. After stimulus presentation, students were asked to type in the result. Corrections were possible. Responses for 21 items were collected (Cronbach's α = .90, EAP reliability = .88). The proportion of correct responses ranged from 7.90% to 71.07%. EAP scores, derived from a 2PL item response model (sample for scaling: N = 639), served as estimates of memory updating.

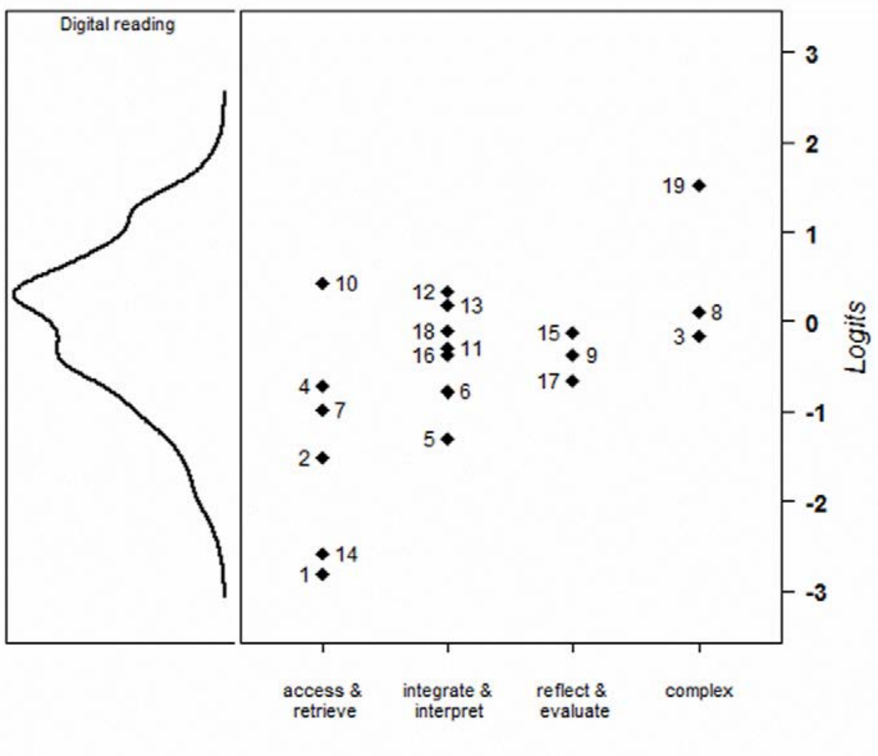

Figure 2. Wright map of the distribution of students' digital reading skills (left) mapped on the same scale as the difficulty of the digital reading items (right). Item difficulties are clustered according to each respective item's reading aspect (x-axis).

2.2.3 Linear reading

Linear reading was measured via 18 items from PISA 2009 (OECD, 2010). The items were clustered into units containing a linear text and three to four items. The texts included different formats (e.g., continuous, non-continuous) and types (e.g., description, narration). The items covered different reading aspects (*access and retrieve*, *integrate and interpret*, *reflect and evaluate*) and reading situations (e.g., public, educational). Examples can be retrieved from http://www.oecd.org/pisa/38709396.pdf. Units were administered either via computer or paper based; no effect of administration mode was found at the construct level (Kröhne, Hahnel, Schiepe-Tiska & Goldhammer, 2013). Response formats included multiple-choice and open text answers. Responses to 16 items were coded dichotomously; three were coded with partial credits. The proportion of respondents receiving full credit on each item ranged from 8.02% to 78.35%. EAP scores, derived from a generalized partial credit model (Nering & Ostini, 2010; N = 880), served as estimates of linear reading (Cronbach's α = .83, EAP reliability = .76).

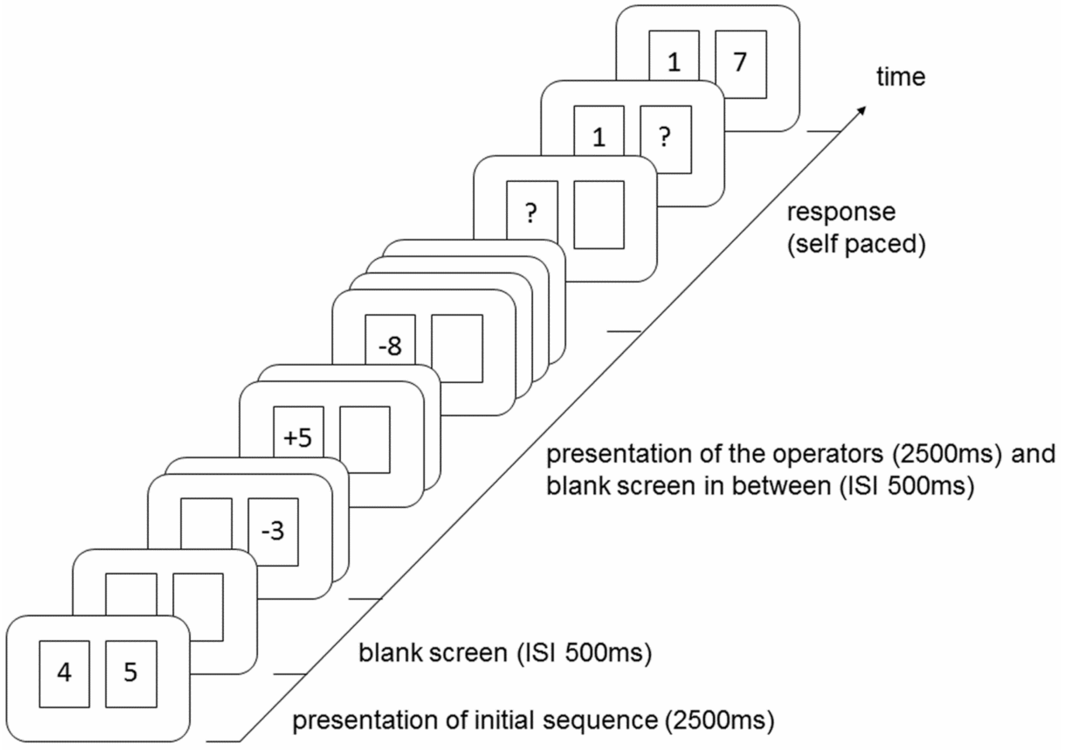

Figure 3. Example of the process of a memory updating item with two digits. The start sequence was presented for 2500ms. After interstimulus intervals (ISI) of 500ms, two operations per digit appeared successively and were presented for 2500ms. Adaptation according to Oberauer and Kliegl (2006, p. 603).

2.3 Procedure

Students participated in groups of 14 on two days and were given instructions by trained test administrators. They were randomly assigned to all test conditions and received comprehensive tutorials. In the digital reading assessment, students received either three or all six digital reading units on the first day. Students participating in the add-on study, which took place within one week of the first testing day, received four linear reading units and then either (1) the other linear reading units, (2) the updating test, or (3) both.

2.4 Data analyses

Generalized linear mixed models (GLMMs; Bolker, et al., 2008; De Boeck et al., 2011) were used to test the hypotheses. Using a logit-link, these models can be used for regressions of the dichotomous digital reading scores on several predictor variables on both the student (i.e., memory updating, linear reading, indicators of node visits and nodes visited) and item level (i.e., reading aspects, number of target and irrelevant nodes). They also can take into account that digital reading scores are hierarchically nested within items, students and schools. In each model, items were modeled as fixed effects (i.e., item easiness), while random effects were modeled for students and schools (i.e., students' digital reading skill and the performance level of a school). Furthermore, each model included a fixed effect of linear reading to account for the effects of general comprehension (cf. Vidal-Abarca et al., 2010).

All analyses were carried out in R 3.1.3 (R Core Team, 2015) with the additional packages *TAM* (Kiefer, Robitzsch & Wu, 2014), *ltm* (Rizopoulos, 2006), *WrightMap* (Irribarra & Freund, 2014), and *lme4* (Bates, Mächler, Bolker & Walker, 2014). All tests were one-tailed, with a Type I error probability of 5%. All metric variables were *z*-standardized. Thus, the regression coefficients are interpretable as predicted changes in the log odds of the probability of giving a correct response if a predictor increases by one standard deviation.

Results

The variances of students' digital reading skills and the performance level of schools in a baseline model without predictors were about 0.52 and 0.98, corresponding to intraclass correlations (ICC1; Skrondal & Rabe-Hesketh, 2004) of 0.14 and 0.23. Table 2 shows descriptive statistics and correlations between the student-specific variables.

3.1 General effect of memory updating

To test the general effect of memory updating (H1), digital reading was regressed on linear reading with and without memory updating. The first model showed that linear reading positively predicted students' success in digital reading tasks (b_1 = 0.71, *z* = 9.97, *p* < .001) and explained a large amount of variance between students (R^2 = .35). The explained variance increased by 7.55% when memory updating was added as a second predictor. Although the predictors were highly correlated (Table 2), memory updating still significantly predicted digital reading (b_2 = 0.26, *z* = 3.85, *p* < .001) after controlling for linear reading (b_1 = 0.59, *z* = 7.39, *p* < .001).

3.2 Variation across task characteristics

A model including interaction effects between reading aspects and memory updating (Table 3) was specified to test whether the memory updating effect on digital reading varies for different cognitive reading operations (H2). The memory updating effect was relatively high for *access and retrieve* items, indicating that students with efficient memory updating had an advantage in such tasks over students with less efficient memory updating. This advantage diminished significantly towards zero for *reflect and evaluate* items. Memory updating had no effect over and above linear reading in tasks requiring the evaluation of a text using one's own knowledge and personal experiences. The effects for *integrate and interpret* as well as *complex* items did not differ significantly from the memory updating effect in *access and retrieve* tasks.

The numbers of target and irrelevant nodes were added as predictors to test whether the memory updating effect increases with the number of target nodes (H3a) and irrelevant nodes (H3b). Although the memory updating effect was still significant (Table 4), the interaction effects with the number of target and irrelevant nodes did not reach statistical significance. The memory updating effect did not increase with the number of target or irrelevant nodes.

Table 2

Descriptive statistics for the individual independent variables and their bivariate correlations (Pearson's r*)*

Independent variable	*M*	*SD*	*Min*	*Max*	1	2	3	4	5
1. memory updating	0.00	0.97	-1.68	2.15	-				
2. linear reading	-0.03	0.82	-1.92	1.84	.50***	-			
3. target nodes visited	2.65	1.05	0.47	5.44	.48***	.58***	-		
4. target node visits	1.57	0.42	0.00	2.33	.37***	.46***	.82***	-	
5. irrelevant nodes visited	0.89	0.76	0.47	4.22	.17**	.12*	.31***	.49***	-
6. irrelevant node visits	0.62	0.43	0.00	2.11	.13*	.05	.25***	.46***	.94***

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

Table 3

Results of the model containing the interaction of memory updating with the number of target nodes and the number of irrelevant nodes

Fixed effects	Estimate	*SE*	*z*	*p*	
linear reading	0.59	0.08	7.40	<.001	***
memory updating (MU)	0.26	0.07	3.86	<.001	***
MU : No. of target nodes	0.05	0.05	0.93	.177	
MU : No. of irrelevant nodes	0.07	0.06	1.16	.123	

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

Table 4

Results of the model containing the interaction of memory updating and the reading aspects

Fixed effects	Estimate	*SE*	*z*	*p*	
linear reading	0.66	0.08	8.26	<.001	***
memory updating (MU)[1]	0.39	0.10	3.80	<.001	***
MU: integrate and interpret	-0.14	0.11	-1.34	.179	
MU: reflect and evaluate	-0.42	0.13	-3.30	<.001	***
MU: complex	-0.12	0.13	-0.93	.355	

Notes. [1] Effect of memory updating for *access and retrieve* items. * $p < .05$; ** $p < .01$; *** $p < .001$.

3.3 Interaction with reader behavior

The indicators of reader behavior were positively correlated (Table 2). The means and the correlations between the unique visit and visit-revisit variables indicate that revisits of nodes seldom occurred for either target or irrelevant nodes. The correlations between the target and irrelevant node visit indicators suggest a tendency among students to explore the hypertext content, regardless of the nodes' relevance.

To test whether the memory updating effect is affected by the number of target nodes accessed (H4a) but diminishes when target nodes are revisited (H4b), two models were specified including unique node visits and repeated visits, respectively. To show that the effects of memory updating do not depend on general navigation behavior, the irrelevant page visits were included in the models (Table 5). The target node visit indicators

Table 5

Results of the models containing the interaction of memory updating with the number of target and irrelevant nodes visited (left model), and the number of target and irrelevant node visits (right model)

Fixed effects	Model with unique visit indicators					Model with visit-revisit indicators				
	Est	*SE*	*z*	*p*		Est	*SE*	*z*	*p*	
linear reading	0.21	0.06	3.50	<.001	***	0.45	0.07	6.06	<.001	***
memory updating (MU)	0.12	0.05	2.34	.009	**	0.19	0.06	3.00	.001	**
visits on target nodes	0.98	0.07	14.58	<.001	***	0.52	0.07	7.25	<.001	***
visits on irrelevant nodes	-0.03	0.05	-0.70	.242		-0.06	0.06	-1.01	.156	
MU : visits on target nodes	0.11	0.05	2.17	.015	*	-0.06	0.06	-1.04	.148	
MU : visits on irrelevant nodes	0.07	0.05	1.41	.080		0.06	0.06	0.99	.160	

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

exhibited a generally positive effect on digital reading. The more target nodes students located, the more likely they were to respond correctly to a digital reading item. In line with our hypotheses, the interaction in the first model showed a significant increase of the memory updating effect with the number of target nodes visited, whereas the interaction with the number of target node visits was not significant. In both models, there were no further effects of the irrelevant node visit indicators on the probability of a correct item response.

Discussion

Digital information resources provide great flexibility for readers to gather information quickly and efficiently. However, processing information that is not presented contiguously can affect comprehension by producing additional load on readers' WM (cf., DeStefano & LeFevre, 2007). Therefore, the present study investigated the effects of memory updating on digital reading. It examined whether the digital reading performance of 15-year-old German students would be predicted by their skill in memory updating. Moreover, this association was considered to be affected by the demands of tasks, hypertexts and actual reader behavior. In summary, the results showed that students benefited from efficient memory updating in their hypertext comprehension over and above linear reading skills. This general effect did not differ between students visiting different amounts of target or irrelevant nodes. It vanished, though, when the task required reflecting on and evaluating text rather than simply extracting text information explicitly or implicitly. Accessing nodes with target information was also shown to accelerate the effect of memory updating, but this interaction effect did not hold when revisits were taken into account.

4.1 Relationship between memory updating and digital reading

Taken together, the results contribute to a growing body of research on the role of WM for hypertext processing. Our findings showed the same relational pattern as studies using other methodological approaches (e.g., Gyselinck et al., 2008; Lee & Tedder, 2003; Naumann et al., 2008): When trying to comprehend hypertext, students benefit from efficient WM functions over and above their linear reading skills. In this respect, the relationship between memory updating and linear reading identified here was in line with previous research on reading and WM capacity (e.g., Dehn, 2008; Oakhill et al., 2011). Reading-related memory processes were taken into consideration in the analyses conducted, adding further evidence in support of the general assumption that decisional and navigational demands in hypertext draw upon WM resources.

Due to the GLMM approach, we were able to elaborate on the role of memory updating in digital reading in more detail by analyzing effects on the task and student levels. Concerning the cognitive reading operations of tasks, memory updating skills seemed to be particularly required when students were instructed to explicitly or implicitly extract information from a hypertext (i.e., *access and retrieve*, *integrate and interpret*) rather than retrieve and use knowledge about texts (i.e., *reflect and evaluate*). That does not mean that memory updating is unnecessary in *reflect and evaluate* tasks, but it is not required above shared processes with linear reading. The effect variation is also not a symptom of task difficulty, as some might suggest. Along with other items, the task difficulty of *reflect and evaluate* items covered an area of average ability in digital reading (Figure 2). We concluded that in information extraction tasks, memory updating skills serve the need to keep text bindings active while locating and evaluating further information in the digital space.

Concerning the number of nodes within a hypertext, there was no support for an interaction with memory updating. It might not be the mere quantity but the quality of information that is crucial. The ease of retaining WM representations can be affected by many other variables, like prior knowledge (Amadieu et al., 2009; Rouet, 2009) or mental integration processes (e.g., chunking or subvocalisation as a form of inner speech; Dehn, 2008). Demands on WM might be relieved, for instance, by maintaining a mental configuration that represents the hypertext structure (Pazzaglia et al., 2008) or establishing coherence between text parts (cf. Kintsch, 1998). Future research needs to address such micro processes of information management and integration in digital reading. Readers' actual interactions with nodes are another explanation for the lack of significant effects. Readers' node selection has previously been shown to interact with their prior knowledge and to affect hypertext comprehension (Salmerón et al., 2005). Our results also showed that the effect of memory updating increased with the number of target nodes accessed. The perception of cognitive load might be influenced by individual behavior to a greater extent than suggested by DeStefano and LeFevre (2007). Regarding the interplay between hypertext and readers' use, the amount of information might affect readers' perception of cognitive load in a differential way depending on their strategies for dealing with a hypertext environment.

Furthermore, the finding that the additional memory updating effect was not found when revisits to target nodes were taken into account is of particular interest. It shows that the impact of an individual skill directly corresponds to specific behaviors observable in log files. It suggests that students with less efficient memory updating skills can compensate for their deficits by consolidating bindings in WM representations through revisits to particular nodes (cf. Walczyk, 2000). An implication might be that students could benefit from training in how to improve their skills in information management or their use of compensatory strategies. However, log files only allowed us to observe when students visited nodes repeatedly. We assumed that readers used revisits for rereading, but what exactly they did in terms of cognitive processing was not traceable. Other reasons may include deficient decoding or self-regulation skills that led to an improper processing of node contents (Foltz, 1996; Vidal-Abarca et al., 2010).

4.2 Limitations

There are at least four major limitations of the present study. First, the specificity of a memory updating effect as an effect of maintaining and manipulating WM content is not completely established. Memory updating tasks have previously been shown to be perfectly accounted for by a WM factor comprising various WM measures on a latent level (Schmiedek et al., 2009). Therefore, it represents a mixture of general WM capacity as well as the specific efficiency of executive processes (Wilhelm et al., 2013). Further investigations should try to avoid mono-operation biases and include other measures of verbal and visuospatial WM (e.g., Gyselinck et al., 2008). Applying a latent modeling approach can then be used to rule out task-specific variance and strengthen the effect interpretations of different WM components and their functions in digital reading.

Second, differences in the interaction effects between memory updating and the node visit indicators might be due to the closed environment of the digital reading units. The hypertexts are merely small, partial simulations of the WWW, and possible actions are limited to the functions provided (e.g., search boxes were visible but did not serve any function). The question arises as to whether revisiting nodes represents a behavior actually conducted in an open web space. Readers often just skim texts for information (Coiro, 2011), and revisits were generally rare events in our data. Closely related to this, the hypertexts also contained only a small number of nodes and did not vary systematically in their structural complexity (e.g., simple tree vs. complex network), or in the availability of maps or other orientation aids (cf. Amadieu et al., 2009). That might have limited the variability in observing revisits.

Third, information is highlighted as relevant through the instruction in tasks (McCrudden & Schraw, 2007). Therefore, the definition of relevance depends on the type of task and reader characteristics. Nodes will not be considered relevant if they do not meet readers' perception of a task that varies as a function of their comprehension skills and prior knowledge. Accordingly, different tasks can trigger readers to modify their navigation behavior and to visit nodes based on different intentions (e.g., rereading an isolated piece of information vs. reviewing for the purpose of integrating information; Rouet, Vidal-Abarca, Erboul & Millogo, 2001). An in-depth examination of node visits under different reading tasks will require further research that includes systematic variations of task types and relevance instructions.

Finally, logit-based GLMMs require dichotomous data that relates to a unidimensional skill. To use this approach, it was necessary to dichotomize six originally partial-credit scored items, even though dichotomization can result in an artificial reduction of variance and a loss of information on individual differences (MacCallum, Zhang, Preacher & Rucker, 2002). The dichotomous responses fit a Rasch model, but the results still raise questions about the unidimensionality of the digital reading construct. From a psychometric point of view, items would be expected to tap into multidimensional skills if their processing required different component skills (e.g., the results of memory updating under different reading aspects). Indeed, the effect pattern is consistent with the provided theoretical background and serves as an indicator of the complex nature of hypertext processing, but it calls the sensitivity of GLMMs into questions, meaning that further research is required.

4.3 Conclusions

Different implications might be drawn for learning and instructional purposes. For learning purposes, the results suggest that readers should learn from hypertext that is designed to be an appropriate fit to their cognitive skills (e.g., by providing optional opportunities for note-taking, scaffolding, or the repetition of central information). For the purpose of instruction, the difficulty of digital reading tasks should be increased gradually to stimulate new strategies and foster integration skills in readers. However, more research is needed to verify such conclusions. Analyzing the processes that lead to particular response outcomes should be a central focus here. Combining performance indicators derived from real web tasks with more fine-grained process data (e.g., eye-tracking or dual task approaches) can be used to validate interpretations about strategies and behaviors from log files.

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References

Amadieu, F., van Gog, T., Paas, F., Tricot, A., & Mariné, C. (2009). Effects of prior knowledge and concept-map structure on disorientation, cognitive load, and learning. *Learning and Instruction*, *19*, 376–386. https://doi.org/10.1016/j.learninstruc.2009.02.005

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2014). *lme4: Linear mixed-effects models using Eigen and S4*. Retrieved from http://CRAN.R-project.org/package=lme4

Bolker, B. M., Brooks, M. E., Clark, C. J., Geange, S. W., Poulsen, J. R., Stevens, M. H. H., & White, J.-S. S. (2008). Generalized linear mixed models: a practical guide for ecology and evolution. *Trends in Ecology and Evolution*, *24*, 127–135. https://doi.org/10.1016/j.tree.2008.10.008

Coiro, J. (2011). Predicting Reading Comprehension on the Internet: Contributions of Offline Reading Skills, Online Reading Skills, and Prior Knowledge. *Journal of Literacy Research : A Publication of the Literacy Research Association*, *43*, 352–392. https://doi.org/10.1177/1086296X11421979

Daneman, M., & Merikle, P. M. (1996). Working memory and language comprehension: A meta-analysis. *Psychonomic Bulletin & Review*, *3*, 422–433.

De Boeck, P., Bakker, M., Zwitser, R., Nivard, M., Hofman, A., Tuerlinckx, F., & Partchev, I. (2011). The estimation of item response models with the lmer function from the lme4 package in R. *Journal of Statistical Software*, *39*, 1–28.

Dehn, M. J. (2008). *Working memory and academic learning: assessment and intervention*. Hoboken, N.J: John Wiley & Sons, Inc.

DeStefano, D., & LeFevre, J.-A. (2007). Cognitive load in hypertext reading: A review. *Computers in Human Behavior*, *23*, 1616–1641. https://doi.org/10.1016/j.chb.2005.08.012

Embretson, S. E., & Reise, S. P. (2000). *Item response theory for psychologists*. Mahwah, N.J: L. Erlbaum Associates.

Engle, R. W. (2002). Working Memory Capacity as Executive Attention. *Current Directions in Psychological Science*, *11*, 19–23. https://doi.org/10.1111/1467-8721.00160

Feldman Barrett, L., Tugade, M. M., & Engle, R. W. (2004). Individual Differences in Working Memory Capacity and Dual-Process Theories of the Mind. *Psychological Bulletin*, *130*, 553–573. https://doi.org/10.1037/0033-2909.130.4.553

Foltz, P. (1996). Comprehension, Coherence, and Strategies in Hypertext and Linear Text. In J.-F. Rouet, J. J. Levonen, A. Dillon, & R. J. Spiro (Eds.), *Hypertext and Cognition* (pp. 109–136). Mahwah, NJ: Lawrence Erlbaum Associates.

Gyselinck, V., Jamet, E., & Dubois, V. (2008). The role of working memory components in multimedia comprehension. *Applied Cognitive Psychology*, *22*, 353–374. https://doi.org/10.1002/acp.1411

Hahnel, C., Goldhammer, F., Naumann, J., & Kröhne, U. (2016). Effects of linear reading, basic computer skills, evaluating online information, and navigation on reading digital text. *Computers in Human Behavior*, *55*, 486–500. https://doi.org/10.1016/j.chb.2015.09.042

Hannon, B. (2012). Understanding the Relative Contributions of Lower-Level Word Processes, Higher-Level Processes, and Working Memory to Reading Comprehension Performance in Proficient Adult Readers. *Reading Research Quarterly*, *47*, 125–152. https://doi.org/10.1002/RRQ.013

Irribarra, D. T., & Freund, R. (2014). *Wright Map: IRT item-person map with ConQuest integration*. Retrieved from http://github.com/david-ti/wrightmap

Kendeou, P., van den Broek, P., Helder, A., & Karlsson, J. (2014). A Cognitive View of Reading Comprehension: Implications for Reading Difficulties. *Learning Disabilities Research & Practice*, *29*, 10–16.

Kiefer, T., Robitzsch, A., & Wu, M. (2015). *TAM: Test Analysis Modules*. Retrieved from http://CRAN.R-project.org/package=TAM

Kintsch, W. (1998). *Comprehension: A Paradigm for Cognition*. Cambridge University Press.

Kornmann, J., Kammerer, Y., Anjewierden, A., Zettler, I., Trautwein, U., & Gerjets, P. (2016). How children navigate a multiperspective hypermedia environment: The role of spatial working memory capacity. *Computers in Human Behavior*, *55*, 145–158. https://doi.org/10.1016/j.chb.2015.08.054

Kröhne, U., Hahnel, C., Schiepe-Tiska, A., & Goldhammer, F. (2013, August). *Analyzing Mode Effects of PISA Print Reading Including a Comparison of Time-related Information.* Presented at the 15th Biennal Conference of the European Association for Research on Learning and Instruction (EARLI), Munich, Germany.

Lee, M. J., & Tedder, M. C. (2003). The effects of three different computer texts on readers' recall: based on working memory capacity. *Computers in Human Behavior*, *19*, 767–783. https://doi.org/10.1016/S0747-5632(03)00008-6

Leu, D. J., Kinzer, C. K., Coiro, J. L., & Cammack, D. W. (2004). Toward a Theory of New Literacies Emerging From the Internet and Other Information and Communication Technologies. In R. B. Ruddell & N. Unrau (Eds.), *Theoretical Models and Processes of Reading* (5th ed., pp. 1568 – 1611). Newark: International Reading Association.

MacCallum, R. C., Zhang, S., Preacher, K. J., & Rucker, D. D. (2002). On the practice of dichotomization of quantitative variables. *Psychological Methods*, *7*, 19–40. https://doi.org/10.1037//1082-989X.7.1.19

Madrid, R. I., Van Oostendorp, H., & Puerta Melguizo, M. C. (2009). The effects of the number of links and navigation support on cognitive load and learning with hypertext: The mediating role of reading order. *Computers in Human Behavior*, *25*, 66–75. https://doi.org/10.1016/j.chb.2008.06.005

McCrudden, M. T., & Schraw, G. (2007). Relevance and Goal-Focusing in Text Processing. *Educational Psychology Review*, *19*, 113–139. https://doi.org/10.1007/s10648-006-9010-7

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The Unity and Diversity of Executive Functions and Their Contributions to Complex "Frontal Lobe" Tasks: A Latent Variable Analysis. *Cognitive Psychology*, *41*, 49–100. https://doi.org/10.1006/cogp.1999.0734

Naumann, J. (2015). A model of online reading engagement: Linking engagement, navigation, and performance in digital reading. *Computers in Human Behavior, 53*, 263-277. https://doi.org/10.1016/j.chb.2015.06.051

Naumann, J., & Goldhammer, F. (2017). Time-on-task effects in digital reading are non-linear and moderated by persons' skills and tasks' demands. *Learning and Individual Differences*, *53*, 1-16. https://doi.org/10.1016/j.lindif.2016.10.002

Naumann, J., Richter, T., Christmann, U., & Groeben, N. (2008). Working memory capacity and reading skill moderate the effectiveness of strategy training in learning from hypertext. *Learning and Individual Differences*, *18*, 197–213. https://doi.org/10.1016/j.lindif.2007.08.007

Naumann, J. & Salmerón. L. (2016). Does navigation always predict performance? Effects of navigation on digital reading are moderated by comprehension skills. *The International Review of Research in Open and Distributed Learning*, *17*, 42-59. https://doi.org/10.19173/irrodl.v17i1.2113

Nering, M. L., & Ostini, R. (Eds.). (2010). *Handbook of polytomous item response theory models*. New York: Routledge.

Oakhill, J., Yuill, N., & Garnham, A. (2011). The differential relations between verbal, numerical and spatial working memory abilities and children's reading comprehension. *International Electronic Journal of Elementary Education*, *4*, 83–106.

Oberauer, K. (2009). Design for a Working Memory. *Psychology of Learning and Motivation*, *51*, 45–100. https://doi.org/10.1016/S0079-7421(09)51002-X

Oberauer, K., & Kliegl, R. (2006). A formal model of capacity limits in working memory. *Journal of Memory and Language*, *55*, 601–626. https://doi.org/10.1016/j.jml.2006.08.009

Organisation for Economic Co-operation and Development (OECD). (2010). *PISA 2009 Assessment Framework*. Paris: OECD Publishing.

Organisation for Economic Co-operation and Development (OECD). (2011). *PISA 2009 Results: Students On Line*. Paris: OECD Publishing.

Organisation for Economic Co-operation and Development (OECD). (2013). *PISA 2012 Assessment and Analytical Framework*. Paris: OECD Publishing.

Organisation for Economic Co-operation and Development (OECD). (2014). *PISA 2012 Technical Report*. Paris: OECD Publishing.

Pazzaglia, F., Toso, C., & Cacciamani, S. (2008). The specific involvement of verbal and visuospatial working memory in hypermedia learning. *British Journal of Educational Technology*, *39*, 110–124. https://doi.org/10.1111/j.1467-8535.2007.00741.x

Perfetti, C., & Stafura, J. (2014). Word Knowledge in a Theory of Reading Comprehension. *Scientific Studies of Reading*, *18*, 22–37. https://doi.org/10.1080/10888438.2013.827687

R Core Team. (2015). *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing.

Rizopoulos, D. (2006). ltm: An R package for latent variable modeling and item response theory analyses. *Journal of Statistical Software*, *17*, 1–25.

Rouet, J.-F. (2006). *The skills of document use: from text comprehension to Web-based learning*. Mahwah, NJ: Erlbaum.

Rouet, J.-F. (2009). Managing cognitive load during document-based learning. *Learning and Instruction*, *19*, 445–450. https://doi.org/10.1016/j.learninstruc.2009.02.007

Rouet, J.-F., Vidal-Abarca, E., Erboul, A. B., & Millogo, V. (2001). Effects of Information Search Tasks on the Comprehension of Instructional Text. *Discourse Processes, 31*, 163-186.

Rouet, J.-F., Vörös, Z., & Pléh, C. (2012). Incidental learning of links during navigation: the role of visuo-spatial capacity. *Behaviour & Information Technology*, *31*, 71–81. https://doi.org/10.1080/0144929X.2011.604103

Salmeron, L., Canas, J. J., Kintsch, W., & Fajardo, I. (2005). Reading Strategies and Hypertext Comprehension. *Discourse Processes*, *40*, 171–191. https://doi.org/10.1207/s15326950dp4003_1

Scheiter, K., Gerjets, P., Vollmann, B., & Catrambone, R. (2009). The impact of learner characteristics on information utilization strategies, cognitive load experienced, and performance in hypermedia learning. *Learning and Instruction*, *19*, 387–401. https://doi.org/10.1016/j.learninstruc.2009.02.004

Schmiedek, F., Hildebrandt, A., Lövdén, M., Wilhelm, O., & Lindenberger, U. (2009). Complex span versus updating tasks of working memory: The gap is not that deep. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *35,* 1089–1096. https://doi.org/10.1037/a0015730

Scott, B. M., & Schwartz, N. H. (2007). Navigational spatial displays: The role of metacognition as cognitive load. *Learning and Instruction*, *17*, 89–105. https://doi.org/10.1016/j.learninstruc.2006.11.008

Skrondal, A., & Rabe-Hesketh, S. (2004). *Generalized latent variable modeling: multilevel, longitudinal, and structural equation models*. Boca Raton: Chapman & Hall/CRC.

Srivastava, P., & Gray, S. (2012). Computer-Based and Paper-Based Reading Comprehension in Adolescents With Typical Language Development and Language-Learning Disabilities. *Language Speech and Hearing Services in Schools*, *43*, 424–437.

Vidal-Abarca, E., Mañá, A., & Gil, L. (2010). Individual differences for self-regulating task-oriented reading activities. *Journal of Educational Psychology*, *102*, 817–826. https://doi.org/10.1037/a0020062

Walczyk, J. J. (2000). The interplay between automatic and control processes in reading. *Reading Research Quarterly*, *35*, 554–566.

Wilhelm, O., Hildebrandt, A., & Oberauer, K. (2013). What is working memory capacity, and how can we measure it? *Frontiers in Psychology*, *4*. https://doi.org/10.3389/fpsyg.2013.00433

Zumbach, J., & Mohraz, M. (2008). Cognitive load in hypermedia reading comprehension: Influence of text type and linearity. *Computers in Human Behavior*, *24*, 875–887. https://doi.org/10.1016/j.chb.2007.02.015

STUDY 2

Publication Note

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Effects of linear reading, basic computer skills, evaluating online information, and navigation on reading digital text

Reading and understanding digital text that is organized in a non-linear hypertext format can be challenging for students as it requires a more self-directed selection of text pieces compared to reading linear texts. This study aims at investigating how individual differences in students' skills in comprehending digital text can be explained by their navigation behavior and various underlying skills. Students' navigation behavior was operationalized by their selection of task-relevant hypertext pages; students' abilities in terms of reading linear texts, dealing with computer interfaces more generally, and evaluating the usefulness of online information were considered as underlying skills. We hypothesized that basic computer skills and evaluating online information would explain performance in digital reading above and beyond reading skills measured with linear texts. These effects were expected to be mediated by navigation behavior. A subsample of 15-year-old German students who participated in the Programme for International Student Assessment (PISA) 2012 was investigated (*N* = 888). The results confirmed the hypothesized mediation between linear reading, navigation behavior, and digital reading. Moreover, navigation behavior also mediated the relation between basic computer skills and digital reading but not the relation between evaluating online information and digital reading. Implications regarding processes in digital reading and navigation of hypertexts are discussed.

Using the Internet to seek information, entertainment, or to communicate has become an integral part of many students' lives, and is a frequent activity both in leisure time and for school-related tasks. Several studies describing adolescents' media usage have shown that around 90% of teens are online and typically use several devices, such as desktop computers, laptops, mobile phones, or tablets (e.g., 88% of German adolescents: Feierabend, Karg & Rathgeb, 2013; 95% of American adolescents: Madden, Lenhart, Duggan, Cortesi & Gasser, 2013; 89% of adolescents in member countries of the Organisation for Economic Co-operation and Development: OECD, 2011). One result of the growing importance of such information and communication technologies (ICT) in society and the labor market has been the inclusion of competencies measuring skills in dealing with digital media in the Programme for International Student Assessment (PISA; OECD, 2012). The PISA study aims at monitoring students' learning and evaluating their preparedness for the challenges of adult life. Therefore, the knowledge, skills, and attitudes of 15-year-olds, who are approaching the end of compulsory education, are regularly assessed in the participating countries. The cross-curricular assessment of reading competency, for instance, is an integral part of PISA because reading is required for written communication and serves as a core ability for long-life learning. However, ICTs have changed the way text is presented and received by readers, which can affect their comprehension of the text and their learning (e.g., Coiro, 2011; Leu, Kinzer, Coiro & Cammack, 2004; Naumann, 2010; Rouet, 2006; Salmerón, Cañas, Kintsch & Fajardo, 2005).

The present study seeks to gain insights into the cognitive skills and processes involved in the comprehension of digital text. In the following, we give a brief overview of (1) the concept and operationalization of digital reading, (2) research on navigation in digital reading, (3) the relations between digital reading, navigation, and skills in reading linear texts, and (4) the role of basic computer skills and evaluating online information in navigating and reading digital text. Finally, the study purpose and hypotheses are presented.

1.1 Digital reading

Digital reading is understood as proficiency in reading and comprehending text that is organized in a digital non-linear format (referred to as “hypertext”). According to the Construction-Integration (C-I) model and its extensions (e.g., Kintsch, 1998; Rouet, 2006; Rouet & Britt, 2010), comprehension of a text is the result of a task-driven construction process in which readers form a so called situation model. The situation model is a mental representation of the situation within a text. It integrates information from the text base and a reader’s own knowledge. Although this construction process should be basically the same for reading text structured both linearly and non-linearly, hypertext imposes further demands on readers regarding their selection of read text pieces (e.g., Boechler, 2001; Coiro, Castek & Guzniczak, 2011; Coiro & Dobler, 2007; Davis & Neitzel, 2012; Naumann, 2010; Naumann, Richter, Christmann & Groeben, 2008; Salmerón et al., 2005).

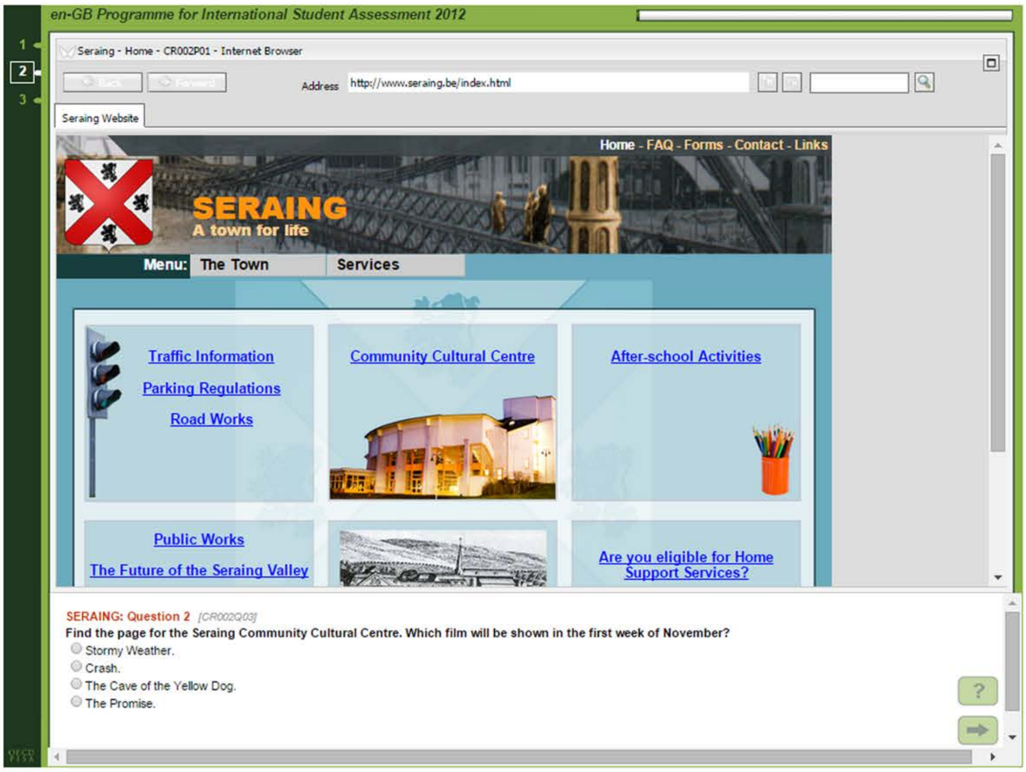
Hypertexts like on the World Wide Web are mainly characterized by a huge information space, separated in several pages. Pages within a hypertext (referred to as “nodes”) are interconnected and accessible through hyperlinks. While a specific page is presented, a huge quantity of other available information – more or less related to a particular topic – is usually not visible. Readers initially do not know how extensive the information space of a particular hypertext is and how it is organized. However, when reading for a specific purpose, readers need to locate and select text parts within the hypertext and create a text base of appropriate quality (cf., Boechler & Dawson, 2005; Gil-Flores, Torres-Gordillo & Perera-Rodríguez, 2012; Leu et al., 2004). In the following, we will use the term digital reading referring to reading skills measured with digital hypertext and the term linear reading referring to reading skills measured with linearly structured texts.

For the assessment of digital reading in PISA, a set of items referring to different types of hypertext were developed (OECD, 2011, 2013). The hypertexts include topics about personal, educational, occupational, and public settings (e.g., official website of a town, private email exchanges, or a social media-like learning platform). For reasons of testing time and efficiency, the hypertexts contain only a limited number of pages (currently up to 33 nodes). Therefore, associated tasks are of short duration and can be completed within a few minutes. The tasks, which students had to perform within the hypertexts, were varied according to the intended text use (e.g., communicating via email, evaluating online news, seeking information about events), text types (e.g., descriptions, argumentations, lists, diagrams), and primary cognitive operations (e.g., finding explicitly stated information, making inferences about implicit relations, reflecting on text content and using it to form an opinion). Figure 1 shows screenshots of two hypertexts. Example (a) presents the homepage of the fictional town Seraing. The task asks students to find out the name of a movie by using the hyperlinks to access the program of the community's cultural center. Example (b) starts with an email exchange between two girls who want to join a fitness studio. In order to complete the presented task, students need to identify the girls' specific needs on the basis of their email exchange and collect arguments from the web pages of suggested fitness studios. Finally, students are asked to recommend a fitness studio by providing two reasons which take the girls' interests into account. These and further examples of PISA digital reading items can be found at http://erasq.acer.edu.au/index.php?cmd=toEra2012 hosted by the Australian Council for Educational Research (ACER).

1.2 Navigation in digital reading

In digital environments, navigation describes a reader's movement through the pages of a hypertext system (Lawless & Schrader, 2008). The navigation metaphor reflects how

(a) Hypertext "Seraing": Locating information about a movie



(b) Hypertext "Sports Club": Recommending a fitness studio

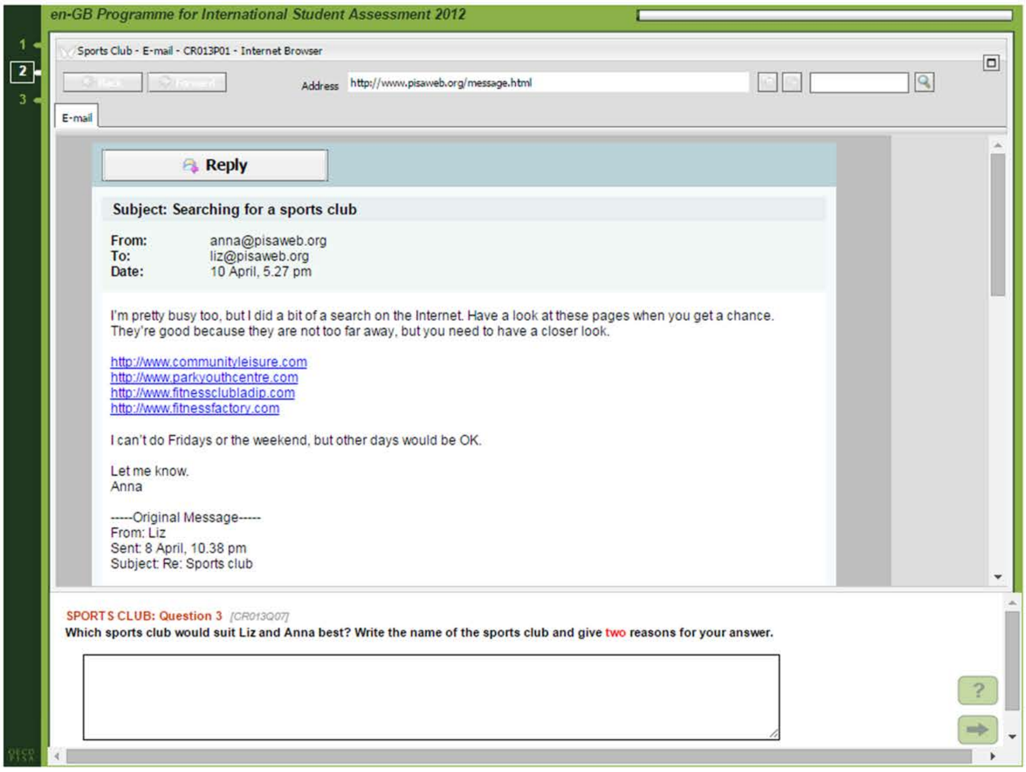


Figure 1. Two examples of digital reading items.

readers access digital text parts and arrange their order to gain information, that is, how readers create their own text base by their selection and sequencing of pages. If readers fail to appropriately navigate through hypertext for a particular reading purpose, they will not locate relevant information. As a result, readers' text base will be less complete and coherent requiring an increased elaboration of knowledge-derived information (cf., Kintsch, 1998). Effective navigation is therefore assumed to be an important predictor of hypertext comprehension and knowledge acquisition. Empirically, navigation strategies and behavior have found to be closely related to successful hypertext reading and learning outcomes (e.g., Lawless & Kulikowich, 1996; Naumann, 2010; Naumann, Richter, Flender, Christmann & Groeben, 2007; Salmerón & García, 2011; Salmerón, Kintsch & Kintsch, 2010).

Operationalizations of navigation behavior are not direct measures of students' cognitive processes but rather the result of them (cf., OECD, 2011). Navigation indicators are frequently extracted from an overwhelming quantity of log-file data recording students' interaction with the computer platform during the test session. Several indicators try to capture students' navigational activity within one measure (cf., Lawless & Kulikowich, 1996; Naumann, 2010) – such as the frequency of task-relevant page visits. Task-relevant pages are defined as (1) pages that provide necessary information for task completion as specified by the item author or (2) pages that need to be passed through in order to access necessary information (OECD, 2011). Task-relevant navigation comprises the act of selecting task-relevant pages. For representing task-relevant navigation, two indicators are often used: (1) the number of relevant page visits and (2) the number of relevant pages visited uniquely. The first indicator counts all visits and revisits of relevant pages; it intends to represent the intensity of readers' engagement with relevant material. The second indicator only regards visits of relevant pages once; it thus represents the comprehensiveness of reader's selection of relevant text.

Task-relevant navigation has been shown to be positively related to digital reading and learning in empirical studies. Naumann and colleagues (2007), for instance, requested that undergraduate psychology students prepare three essays on topics about visual perception (e.g., an essay about "Important studies on perception of space"). The students had one hour to learn with an expository hypertext, which was hierarchically structured and contained about 230 pages and 540 cross-references. According to the essay's topic, the number of relevant pages varied from 27 to 31 pages. The authors found significant correlations between students' number of relevant page visits and different learning outcomes (*r*=.30-.52). In the PISA 2009 digital reading assessment (OECD, 2011), task-relevant navigation was also highly predictive of students' digital reading performance across participating countries (number of relevant page visits: *r*=.39-.75, OECD average: *r*=.62; number of relevant pages visited: *r*=.68-.86, OECD average: *r*=.81). Furthermore, task-relevant navigation significantly accounted for variance in digital reading performance over and above skills in reading linear text. In the next section, the relationship between linear reading, navigation behavior, and digital reading is outlined in more detail.

1.3 Linear reading, navigation, and digital reading

Reading skills measured with linear text are supposed to affect students' navigational decisions and consequently their comprehension of digital text (Lawless & Schrader, 2008; Naumann et al., 2007, 2008; Rouet, Ros, Goumi, Macedo-Rouet & Dinet, 2011; Salmerón & García, 2011). Linear reading enables readers to identify and relate important ideas in texts, and to monitor their own comprehension progress. Therefore, readers who are competent in reading linear text are expected to interpret and connect important ideas presented on nodes in the hypertext, and to reread particular pages if they detect gaps in their comprehension. In contrast, less able readers might have problems extracting important facts from web pages, relating main ideas between different pages, or making inferences based on the connections between text information, background knowledge, and their reading goal. As a result, they might select pages less effectively than able readers, leading to restricted hypertext comprehension. In a study with 33 Spanish sixth graders, Salmerón and García (2011) investigated the relations between students' (linear) reading skills, navigation strategies, and hypertext comprehension. Students were asked to read a hypertext about daily life in Ancient Rome. The hypertext was hierarchically tree-structured with 20 nodes. The authors found that the navigation path of able linear readers showed higher semantic overlap between the nodes visited, which was associated with better comprehension of the hypertext. Besides this indirect effect, a direct effect of linear reading on digital reading also remained, which might be based on comprehension processes not reflected in navigation (e.g., integration of readers' knowledge). Salmerón and García concluded that reading skills facilitate the identification and connection of main ideas between various hypertext nodes, allowing readers to follow a more conclusive navigational path. In the next section, this mechanism is further distinguished from the effects of ICT-related component skills in digital reading.

1.4 The role of ICT-related skills

While linear reading skills enable students to deal with the content of hypertext, the need for ICT-related skills results from the use of the digital medium (cf., Boechler & Dawson, 2005; Gil-Flores et al., 2012; Leu et al., 2004). From a technical view, students need skills enabling them to deal with computer interfaces in general. These fundamental skills are described as basic computer skills (Goldhammer, Naumann & Keßel, 2013), which comprise actions of accessing, collecting, and providing information on a computer interface (e.g., using well-established navigation devices like arrow buttons, managing information with bookmarks, editing text, sending emails). Basic computer skills refer more to behavioral skills than to explicit factual knowledge about computers. Highly skilled and practiced students are therefore supposed to possess general knowledge about structures and functionalities in computer environments which is independent of particular applications or evolved versions. When interacting with digital text, well-developed general concepts of hypertext structures and control functions (e.g., browser controls like back and next buttons; text-inherent controls like hyperlinks) should support students in locating, accessing, and managing information within a hypertext (cf., Boechler & Dawson, 2005; Gall & Hannafin, 1994; Leu et al., 2004; Waniek, Brunstein, Naumann, & Krems, 2003). If students, however, lack such basic skills, they will miss pages or devote time and cognitive resources to trying to find access. Empirically, Goldhammer, Naumann, and Keßel (2013) found strong positive relations between basic computer skills and digital reading for the German sample of the PISA 2009 field test. Basic computer skills accounted for 38% of the variance in digital reading. Naumann (2010) further showed that this impact was distinguishable from the effects of linear reading since both linear reading and basic computer skills predicted digital reading significantly. Additionally, he found that basic computer skills were related to students’ navigation behavior: The probability of students’ success in digital reading tasks rose with higher values in basic computer skills but increased even more when students also visited more task-relevant pages. This interaction might also be interpreted in that students showed more effective information management when they possessed better basic computer skills. Well-developed basic computer skills would then support efficient path tracking and keeping one's orientation in digital text.

From a cognitive view on the use of ICTs, students need skills in evaluating online information to be successful in digital reading. Particularly on the web, information can be incomplete or unreliable, requiring students to reflect on information carefully (Brand-Gruwel, Wopereis & Walraven, 2009; Walraven, Brand-Gruwel & Boshuizen, 2009). Evaluating online information describes students' skills in using structural and message-based features of hyperlinks and their corresponding web pages to judge the relevance, credibility, and utility of sources when seeking information online (cf., Goldhammer, Keßel & Kröhne, 2013; Rieh, 2002). Structural features address basic elements of the composition of hyperlinks and web pages (e.g., layout of a web page, advertisement banners, suffixes indicating a specific top-level domain like .org, .edu, .com); message features address quality attributes of the presented text itself (e.g., authority, currency, scope). Hypertexts require readers to make efficient decisions about which information could potentially contribute to their reading goal and should therefore be processed. Readers need to apply inferential strategies and make forward predictions in order to efficiently differentiate between relevant and ignorable information (Coiro et al., 2011; Davis & Neitzel, 2012; Naumann et al., 2008; Rieh, 2002). In case studies, Coiro and Dobler (2007) observed sixth graders with high verbal skills performing information search tasks on the World Wide Web. They found that students applied a set of strategies specific to reading digital texts. Among others, these strategies included scanning and skimming pages in search of relevant information and using hyperlinks to predict upcoming text material. Evaluating online information comprises such heuristics and strategies with regard to decisions such as whether a certain hyperlink should be clicked upon or whether the content of an accessed web page should be processed in depth. If a hyperlink, for instance, does not seem to hold much promise with regard to a specific reading goal, readers will probably decide to pass by the connected web page. Providing students with guidance on following particular hyperlinks can improve their hypertext comprehension, as was shown by Madrid, Van Oostendorp and Puerta Melguizo (2009). They compared undergraduates who read a hypertext with 21 pages on neuropsychology and a hyperlink list on the left screen side with undergraduates who read the same hypertext with some hyperlinks marked by double-arrows “>>”. The marked hyperlinks indicated the pages most closely related to the current page in terms of content and therefore provided a direct hint of an optimal reading path. The authors found that undergraduates in the marked hyperlink condition showed more coherent text selection and scored higher on inference questions than undergraduates in the control condition. The marked hyperlinks might have relieved the need for forward predictions and navigational decision-making in undergraduates, therefore supporting their comprehension of the provided hypertext.

1.5 The present study

Reading and understanding digital text is an important skill when textual information is received from digital media. Therefore, it is necessary to deepen our knowledge about factors and processes that can support or hinder hypertext comprehension. This will also provide information on how to prepare students to deal appropriately with digital information. The present study investigated how individual differences in 15-year-old students' comprehension of digital text can be explained.

To form an understanding of a hypertext, students need to be able to identify and relate important ideas from hypertext pages. Hypertexts, though, require readers to locate and evaluate text parts in a more self-directed way compared to linear texts. Hence, readers additionally need to know (1) how to technically use a hypertext and (2) how to effectively determine the usefulness of online information. We therefore hypothesized:

(1) Higher scores in linear reading, basic computer skills, and evaluating online information predict higher scores in digital reading, with each predictor accounting for unique variance.

We assume that the predictors in Hypothesis 1 not only affect digital reading but also influence students' task-relevant navigation, that is, their behavior in identifying text as relevant for a pursued reading purpose. As we also expect that the task-relevant navigation predicts digital reading, we derived the following three mediation hypotheses to investigate these processes in more detail. First, competent readers should extract the contents of hypertext pages and meaningfully link them according to a specific reading goal. Consequently, they should engage with a hypertext in a more task-oriented way than weak readers, resulting in more intense and comprehensive task-relevant navigation and better comprehension. Linear and digital reading will still show a further association since text comprehension also requires other processes like the establishment of coherence or the integration of knowledge. Salmerón and García (2011) found a similar relational pattern for sixth graders, which should also hold for 15-year-old adolescents who possess more highly developed reading skills. We hypothesized:

(2) Task-relevant navigation mediates the effect of linear reading on digital reading, but a direct effect of linear reading also remains.

Second, well-developed basic computer skills allow one to use and traverse digital environments in a flexible way. Therefore, they should enable students to fluently locate, access, and re-access web pages with relevant content. Furthermore, this means of generating an appropriate text base should indirectly empower students to better comprehension of digital text. We hypothesized:

(3) Task-relevant navigation mediates the effect of basic computer skills on digital reading.

Third, evaluating online information supports students in differentiating effectively between useful and ignorable information in terms of its relevance and credibility. Well-developed skills in evaluating online information thus should enable students to efficiently distinguish between task-relevant and task-irrelevant pages. Consequently, they should select pages contributing to their reading goal. We hypothesized:

(4) Task-relevant navigation mediates the effect of evaluating online information on digital reading.

Method

2.1 Sample

A total sample of 888 students ranging in age from 15 to 16 years (*M* = 15.82, *SD* = 0.29) participated. The sample included 48.4% female and 51.6% male students from 77 schools. The students participated in both the PISA 2012 main study and a German extension study investigating questions related to computer-based assessment (CBA) in PISA. The sampling procedure consisted of two stages in which 212 PISA-eligible schools were first sampled and afterwards 25 students were drawn randomly from each selected school (further information on the sampling scheme can be retrieved from OECD, 2014).

2.2 Measures

2.2.1 Digital reading

Digital reading was assessed with 19 items embedded in six different simulated hypertext environments. Each hypertext contained two to four items and sets of three hypertexts were organized into clusters. Therefore, a total of two clusters were built containing ten and nine items, respectively. Since some students processed the content of both clusters as assigned by a random group design (see Section 2.3, Procedure), students' performance in the two clusters could be compared. The hypertexts contained 9 to 33 nodes which included 1 to 10 task-relevant pages. Each available navigation device (i.e., hyperlinks, menus, and tabs) was clickable and led to another page. Students could move freely between all pages of a particular hypertext environment. The items were displayed at the bottom of the hypertext (see Figure 1).

Response formats included multiple choice (12 items), open text (4 items), and mixed forms (3 items). Open text responses were scored by coders recruited, trained, and supervised by the Data Processing and Research Center (DPC) in Hamburg, Germany, which is part of the International Association for the Evaluation of Educational Achievement (IEA). The coders evaluated the responses according to provided standardized coding guidelines, which were developed by means of several pre-test and review phases (OECD, 2014). The guidelines included a list of possible response categories for each item as well as a scoring code, descriptions on kinds of responses for which a particular code should be assigned, and response examples for each code category. Students' responses in six items were scored using a partial-credit system (2 = full credit, 1 = partial credit, and 0 = no credit). The remaining items were scored dichotomously (1 = full credit and 0 = no credit). Quality checks were made on a regular basis, for instance, through multiple coding of a random selection of responses by four independent coders. If multiple coding revealed low consistency between the coders, the international PISA Consortium was contacted to identify the causes of the discrepancy. That was not the case for any item in Germany (Prenzel, Sälzer, Klieme & Köller, 2013).

For the examination of statistical item and scale properties, the proportion of students receiving full credit in an item and item-test correlations were determined per item. The proportion ranged between 14.0 and 95.7%, suggesting a broad range in item difficulties. Item-test correlations ranged from .29 to .55, which indicates acceptable item discrimination. Reliability was determined for items (Cronbach's α = .82) and item parcels (see 2.4 Data analyses; McDonald's ω_t = .83; Revelle & Zinbarg, 2009).

2.2.2 Task-relevant navigation

Students' movement through a digital reading item was recorded in log files. Both the number of relevant page visits and the number of relevant pages visited as defined above (see Section 1.2, Navigation in digital reading) were extracted for each student and each item, and then averaged across items. The resulting two indicators represented task-relevant navigation (cf., OECD, 2011). Note that the log data for six items were excluded from creating the indicators because the completion of these six tasks did not require navigation between pages. As an operationalization check, we computed the average number of relevant page visits for the excluded six (non-navigation) items as well as for the remaining (navigation) items, and correlated them. The resulting correlation about .16 confirms that the excluded six items do not consistently contribute to the construction of a navigation indicator. Since the standard deviation of the number of relevant pages visited for the non-navigation items was zero, a comparable operationalization check was not possible.

2.2.3 Linear reading

Linear reading was assessed by 29 reading items from two clusters used in PISA 2009. Each cluster was time restricted to 30 minutes and contained four units, that is, an item stem (e.g., a play, expository text about acne, argumentation about mobile phone safety) with three to four comprehension questions about the content of the stem. The items were designed with regard to different reading focuses ("access and retrieve", "interpret and integrate", "reflect and evaluate"), reading situations (e.g., personal, public, educational), and text formats (e.g., sentences, paragraphs, lists, tables, diagrams), but were not intended to constitute discrete subscales. Several item examples can be retrieved from the OECD website (http://www.oecd.org/pisa/38709396.pdf).

Response formats included multiple choice (14 items) and open text answers (15 items). Coding open text responses was conducted similarly as was the case for the digital reading open text responses. Four items were scored using a partial-credit system; the others were scored dichotomously. The proportion of students receiving full credit ranged from 1.30 to 78.4%. Items showed acceptable discriminations (.22-.60), except for one item that did not contribute to the accuracy of measurement (discrimination = .09). Reliability was good (α = .88, ω_t = .87).

2.2.4 Basic computer skills

Basic computer skills were measured by a revised version of the Basic Computer Skill Scale (Goldhammer, Naumann, et al., 2013). This scale assesses fundamental skills in dealing with computer interfaces using 20 interactive items. In prototypical computer environments (e.g., simulated word-processing software, web browser, or email clients), students had to solve every-day computer tasks like opening and saving a file, finding information on a webpage through scrolling, using hyperlinks to access information, or editing text entries. In the example presented in Figure 2, for instance, students were asked to go back to the previous page. A correct response required students to click on the back button (i.e., left arrow) or to use the browser history, reflecting basic actions in using web browsers. Students were asked to work as accurately and quickly as possible. Their responses were coded dichotomously. The proportion of students solving the items correctly ranged from 15.3 - 83.6%. Item discriminations (.28-.57) as well as reliability (α = .85, ω_t = .85) were acceptable.

2.2.5 Evaluating online information

Students' skill in evaluating online information was assessed by the Test for Evaluation of Online Information (Goldhammer, Keßel, et al., 2013). This test contains 16 items which simulate a search engine results page (SERP) with a list of hyperlinks. Students received problem-focused tasks (e.g., preparing a talk on migraine headaches for biology class or looking for information about how to change a bicycle chain) and were asked to select the hyperlink from the SERP most likely to provide credible and useful information. The number of entries in the simulated SERP varied between items from three to ten sources. The provided information for each entry in the SERP were varied in terms of the occurrence of structural and message-based features, the attractiveness of distractor links, and the congruency of the hyperlink and corresponding web page with respect to trustworthiness. In the example in Figure 3, students were asked to identify which hyperlink would lead to a web page providing information about paragliding risks. To solve this task, students needed to identify the message-based intent of the three provided SERP entries (here [1] offering lessons, [2] selling gift vouchers, [3] providing information about the sport). Students were instructed to work as accurately and quickly as possible. The responses were coded dichotomously. The proportion of students correctly completing each item ranged from 9.0 - 55.2%, showing that the items were rather difficult. Item discriminations were acceptable (.26-.49), except for two items presenting lower discrimination (.07 and .15, respectively). Reliability was acceptable (α = .75, ω_t = .75).

2.3 Procedure

The assessment of digital reading was part of the computer based assessment (CBA) of the PISA 2012 main study. The assessment was divided into a comprehensive 20-minute tutorial and a 40-minute test part. Figure 4 (a) outlines the timeline (horizontal) and different test conditions (vertical). Students participating in the CBA received either (1) both digital reading clusters, (2) one digital reading cluster, or (3) did not participate in the digital reading assessment at all. The cluster content was assigned randomly. In one

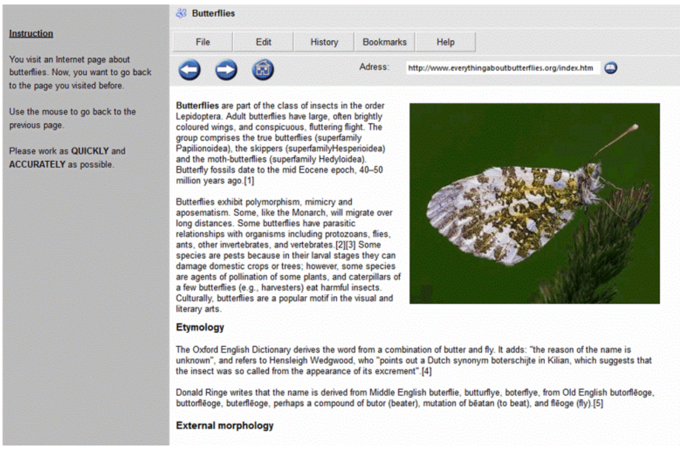


Figure 2. Example of a basic computer skill item: Using a back button. See Appendix D for references on text and artwork.

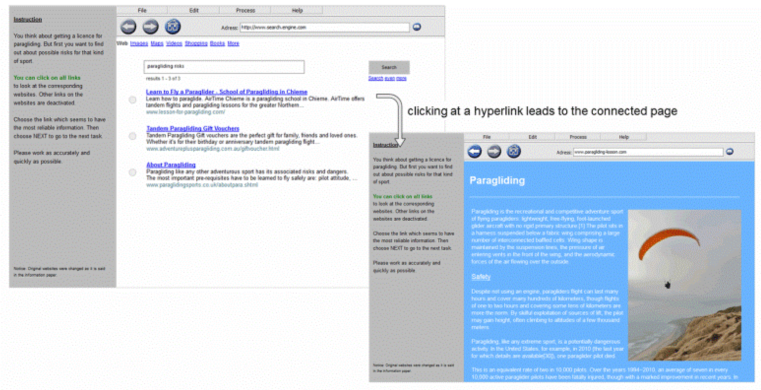


Figure 3. Example of an item measuring evaluating online information: Paragliding risks. See Appendix D for references on text and artwork.

session, a maximum of 14 students were assessed and instructed by trained test administrators. The computer-based tests were delivered to schools via USB sticks or laptop sets if adequate computer equipment was not in the selected school.

The assessment of linear reading, basic computer skills, and evaluation of online information was carried out as part of a national extension of the PISA study in Germany. It took place on an additional test day no later than one week after the main assessment. A maximum of 14 students were tested during one session using prepared laptops. Total testing time was restricted to 120 minutes. As outlined in Figure 4 (b), all students were asked to complete one reading cluster at session begin. The cluster content was randomly assigned. Afterwards, students received either (1) the second linear reading cluster, the Basic Computer Skill Scale, and the Test for Evaluation of Online Information, (2) the second linear reading cluster only, or (3) the ICT-related tests only. Note that for the investigation of measurement invariance between computer and paper-based assessment at the item-level, linear reading was administered in a randomized balanced within- and

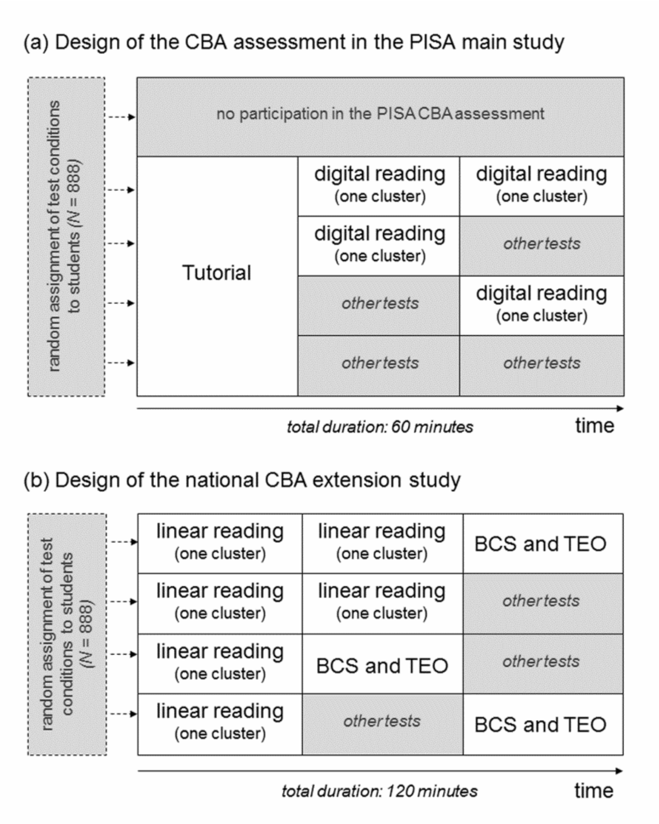


Figure 4. Schematic overview of the design and timeline of (a) the computer based assessment (CBA) in the PISA main study and (b) the national CBA extension study. BCS = Basic Computer Skill Scale. TEO = Test for Evaluation of Online Information.

the item-level, linear reading was administered in a randomized balanced within- and between-group design, and half of the sample answered items from both modes (Kröhne, Hahnel, Schiepe-Tiska & Goldhammer, 2013). All tests contained comprehensive tutorials as well as practice tasks to familiarize students with the test structure, functionalities of response formats, and interface for computer-based items.

2.4 Data analyses

To test the hypotheses, item parcels were created and subsequently used in latent regression and mediation models (cf., Kline, 2011; MacKinnon, 2008). Item parcels are aggregated response indicators that comprise the sum of individual responses over two or more items. They are often used to conduct structural equation models because parcels provide psychometric merit to the modeling of multivariate data (Little, Cunningham, Shahar & Widaman, 2002). Parceling requires that the items of the respective scale approve to measure a single skill dimension. Since this could be shown (see scree plots in Appendix A), parcels were built for digital reading, linear reading, basic computer skills, and evaluating online information. Items were combined into parcels according to the item-to-construct-balance approach (Little et al., 2002), that is, parcels were equally balanced in terms of their difficulty and discrimination. The number of parcels was chosen so as to evenly distribute the number of items over parcels. The linear reading items were parceled over the computer and paper-based assessment modes. By ignoring the administration mode at the parcel level, we expect that the estimates of the relation between linear and digital reading are not affected by construct-irrelevant influences of the mode.

Latent regression and mediation models are a form of structural equation models, which are a statistical technique to test confirmatory models (cf., Kline, 2011). They include unobserved latent variables, which are defined by observed manifest variables according to a linear measurement model, and a structural regression model defining the relations among the latent variables. The created item parcels were used as congeneric indicators for latent variables representing each individual skill. Task-relevant navigation behavior was specified as a manifest variable. Since the number of relevant pages visited is a subset of the number of relevant page visits, analyses were conducted separately. The analyses showed identical relational patterns for models including the number of relevant page visits and models including the number of relevant pages visited. Hence, only the results of models including the number of relevant visits are reported in the following. The results of the models including the number of relevant pages visited are summarized in Appendix C.

When conducting the mediation models, we computed additionally the coefficient κ^2 for significant indirect effects (Preacher & Kelley, 2011). This coefficient takes regression weights as well as variances and covariances of predictor, mediator and criterion variables into account in order to estimate the effect size of an indirect effect. According to Preacher and Kelley, values at .01, .09, and .25 can be interpreted as small, medium, and large effects, respectively.

The rates of missing data were below 8 % for each parcel (digital reading: 5.39 - 7.62%; linear reading: 2.36 - 3.44%; basic computer skills: 3.81 - 3.96%; evaluating online information: 3.96 - 4.41%). Assuming that parcels are normally distributed indicators and missing data is missing at random (MAR; van Buuren, 2012), parameters were estimated with full information maximum likelihood (FIML) using Mplus 7 (Muthén & Muthén, 1998-2012). FIML is a missing data technique that maximizes the "casewise likelihood function using only those variables that are observed for case *i*" (Enders & Bandalos, 2001, p. 434). That means that missing data is not imputed on the student level but that the estimation of parameters includes all available data. Compared to other methods for dealing with missing data in structural equation models (e.g., listwise deletion, pairwise deletion, and similar response pattern imputation), Enders and Bandalos (2001) recommend the use of FIML as the superior method since it provides unbiased, efficient estimates as well as stable Type I error rates.

Results

The results of the latent analyses conducted are described in this section. Table 1 presents descriptive statistics for the item parcels and their standardized loadings on the latent variables with standard errors. According to common criteria (Kline, 2011), the parcel model fits well (χ^2 (180) = 239.89, p = .002; RMSEA = .02, CFI = .99, TLI =. 99, SRMR = .04). Correlations within as well as between parcels and the navigation indicators can be found in Appendix B. All latent variables and navigation indicators were correlated positively and significantly (table 2). In the description of results that follows, standardized coefficients are reported.

3.1 Digital reading and navigation

On average, students visited and revisited about five to six relevant pages per item (*M* = 5.53, *SD* = 2.61, *Min* = 0.75, *Max* = 13.20). Figure 5 displays the relation of task-relevant navigation and digital reading. In the model without the cognitive predictors (χ^2 (14) = 27.65, *p* = .02; RMSEA = .05, CFI = .98, TLI =. 97, SRMR = .04), the number of relevant page visits was strongly predictive of digital reading performance ($\hat{\beta}$ = .80, *SE* = 0.03, *p* < .001). An increase of one standard deviation in the navigation indicator resulted in an increase of .80 standard deviations in digital reading, that is, students who visited more pages containing task-relevant contents received higher scores in digital reading. The model already explained a high proportion of the variance in digital reading scores (64.2%).

3.2 Digital reading, linear reading, and ICT-related skills

To test the specific impact of ICT-related skills in digital reading above and beyond reading skills, three latent multiple regression analyses were conducted, with each including one more cognitive predictor. Table 3 shows the results of the regression models. In Model 1 (χ^2 (166) = 240.02, *p* < .001; RMSEA = .05, CFI = .98, TLI =. 98, SRMR = .05), digital reading was regressed on linear reading scores, which strongly predicted students' comprehension of digital text. Students with higher scores in linear reading skills also achieved higher scores in digital reading tasks. In Model 2 (χ^2 (165) = 214.13, *p* < .01; RMSEA = .02, CFI = .99, TLI =. 99, SRMR = .04), basic computer skills were added as a predictor. Both linear reading and basic computer skills predicted digital reading scores positively. Students with higher scores in linear reading and basic computer skills, respectively, both showed better performance in digital reading. Finally, evaluating online information was included additionally in the third model (χ^2 (164) = 209.09, *p* = .01; RMSEA = .02, CFI = .99, TLI =. 99, SRMR = .04). This analysis revealed positive and significant relations for all predictors. Students benefitted in their comprehension of digital text when they also achieved higher scores in their linear reading skills, basic computer skills, and online-information evaluating skills. Note that the regression coefficients have shrunk with each following model, as is expected because of the shared variance of the predictors (cf., Table 2). Summing up, the inclusion of both ICT-related skills as predictors in addition to linear reading was able to explain an additional 13.7% of the variance in digital reading.

Table 1

Descriptive statistics and standardized loadings of parcels

Latent variable	Parcel	N_{items}	*M*	*SD*	*Min*	*Max*	$\hat{\lambda}$
Digital reading	1	3	1.73	1.38	0	5	.68 (.04)
	2	3	2.32	1.23	0	4	.70 (.04)
	3	4	2.41	1.20	0	4	.78 (.03)
	4	3	2.32	1.29	0	4	.72 (.03)
	5	3	2.44	1.18	0	4	.66 (.04)
	6	3	2.27	1.16	0	4	.60 (.04)
Linear reading	1	6	2.84	1.60	0	7	.69 (.02)
	2	6	2.95	1.79	0	7	.81 (.02)
	3	6	3.00	1.71	0	7	.72 (.02)
	4	6	2.21	1.48	0	7	.67 (.02)
	5	5	2.00	1.43	0	5	.78 (.02)
Basic computer skills	1	4	2.01	1.13	0	4	.75 (.02)
	2	4	2.15	1.07	0	4	.65 (.03)
	3	4	2.34	1.08	0	4	.76 (.02)
	4	4	2.39	1.18	0	4	.75 (.02)
	5	4	2.44	1.22	0	4	.75 (.02)
Evaluating online information	1	4	1.39	1.08	0	4	.74 (.03)
	2	4	1.40	1.05	0	4	.62 (.03)
	3	4	1.22	1.08	0	4	.65 (.03)
	4	4	1.15	1.04	0	4	.65 (.03)

Notes. Standard errors of parcel loading are written in parentheses. All loadings were significant at $p < .001$.

3.3 The mediation model

To test the explanatory impact of navigation, two latent mediation models investigating the effects of linear reading and both ICT-related skills on digital reading through task-relevant navigation as a mediator were specified. The mediation model explained a large proportion of the variance in digital reading ($R^2 = .81$). Note that the total effects in these models correspond to the regression results found in the third regression model, which included linear reading and ICT-related skills as predictors for digital

Table 2

Standard deviation (SD) of and correlations between latent variables and the number of relevant page visits

	SD	DR	LR	BCS	EOI
Digital reading (DR)	0.97				
Linear reading (LR)	1.09	.71			
Basic computer skills (BCS)	0.86	.72	.70		
Evaluating online information (EOI)	0.80	.71	.71	.75	
Relevant page visits and revisits	2.61	.80	.50	.52	.47

Note. All correlations were significant at $p < .001$.

Table 3

Results of latent regressions of digital reading gradually including the cognitive predictor skills (standardized coefficients)

Model	1		2		3	
Predictor	LR		+ BCS		+ EOI	
$\hat{\beta}_{LR}$	.71 (.04)	***	.42 (.08)	***	.32 (.09)	***
$\hat{\beta}_{BCS}$			.43 (.08)	***	.31 (.10)	**
$\hat{\beta}_{EOI}$					.26 (.11)	*
R^2	.50		.61		.64	

Notes. LR = Linear reading. BCS = Basic computer skills. EOI = Evaluating online information. Standard errors of regression coefficients are written in parentheses. * $p < .05$, ** $p < .01$, *** $p < .001$.

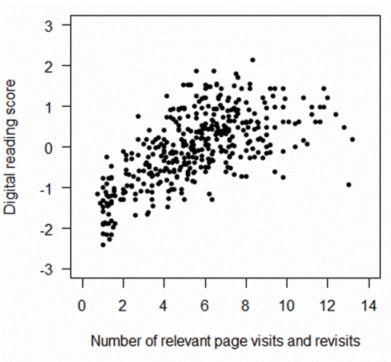


Figure 5. Scatter plot of students' digital reading performance and the number of relevant page visits.

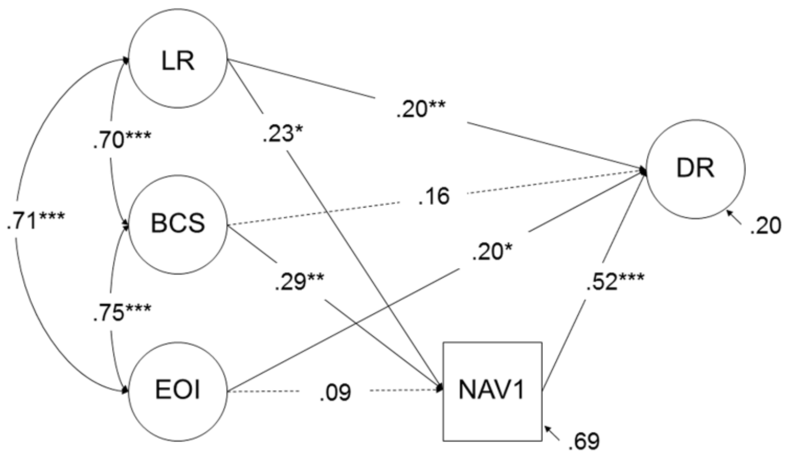


Figure 6. Estimated mediation model with standardized regression coefficients. LR = Linear reading. BCS = Basic computer skills. EOI = Evaluating online information. NAV1 = Number of relevant page visits. DR = Digital Reading. Solid arrows describe significant paths; dashed arrows describe non-significant paths.

reading (see last column in Table 3). Figure 6 shows the results of the mediation model what follows in a path diagram.

The number of visits to relevant pages was predicted directly by linear reading ($\hat{\beta}$ = .23, *SE* =.09, *p* = .01) as well as basic computer skills ($\hat{\beta}$ = .29, *SE* = .10, *p* = .002). Students' skill in evaluating online information had no significant relation to task-relevant navigation ($\hat{\beta}$ =.09, *SE* = .11, *p* = .44) for any given value of linear reading and basic computer skills. These results show that students visited more pages with task-relevant content when they were better readers and had more routinized basic computer skills. Students' skill in evaluating online information, however, had no additional predictive value for task-relevant navigation. The number of task-relevant page visits had a direct effect on digital reading ($\hat{\beta}$ = .52, *SE* = .05, *p* < .001), that is, students who visited more relevant pages achieved higher digital reading scores.

In the following paragraph, the indirect effects of linear reading, basic computer skills, and evaluating online information on digital reading through the number of relevant page visits are reported. The remaining direct effects of the cognitive predictors on digital reading are reported as well. For linear reading, a significant indirect effect ($\hat{\beta} = .12, SE = .11, p = .013, \kappa = .15$) of medium effect size was found. Students with higher scores in linear reading visited more pages with relevant content, which resulted in higher digital reading scores. Indeed, the direct effect of linear reading skills decreased

($\hat{\beta} = .20, SE = .08, p = .009$) but remained significant, that is, higher scores in linear reading still accounted for higher digital reading scores over and above the explanatory value of the number of relevant page visits. Concerning basic computer skills, a medium indirect effect ($\hat{\beta} = .15, SE = .05, p = .003, \kappa = .19$) was found. Students who achieved a higher score in basic computer skills visited more task-relevant pages and performed better in reading digital text. The remaining direct effect was not significant ($\hat{\beta} = .16, SE = .09, p = .067$). Finally, we found no indirect effect of evaluating online information on digital reading through the number of relevant page visits ($\hat{\beta} = .05, SE = .06, p = .434$). However, there was a significant direct effect ($\hat{\beta} = .20, SE = .10, p < .037$), indicating that evaluating online information still accounted for variance in digital reading that is not related to linear reading, basic computer skills, or task-relevant page visits.

Discussion

Reading and understanding digital hypertexts is a complex process that exceeds the demands readers have to meet when reading linear text (e.g., Coiro & Dobler, 2007; Leu, et al., 2004; Naumann, 2010; Rouet, 2006). In this study, we investigated which individual skills contribute to the prediction of students' digital reading performance and whether these relations were mediated through students' task-relevant navigation behavior in hypertexts. We expected students' basic computer skills and their skill in evaluating online information to explain variance in their digital reading scores over and above their comprehension of linearly structured text. Furthermore, we hypothesized that these three relations are mediated through students' behavior in visiting hypertext pages with task-relevant content. The results support the hypotheses partly. In confirmation of our hypotheses, we found linear reading and both ICT-related skills to account for significant amounts of unique variance in digital reading. The relation from linear reading to digital reading was partially mediated through students' navigation behavior; the relation from basic computer skills to digital reading was completely mediated. Contrary to our hypotheses, however, the relation between evaluating online information and digital reading was not mediated through students' task-relevant navigation behavior. In the following section, we first discuss our results in relation to previous findings and try to place them in an appropriate context. Second, we outline some important limitations of this study, discuss their impact on the interpretation of the results, and encourage further investigations in the field.

4.1 Prerequisites of digital reading

Considering linear reading, the partial mediation found in this study is consistent with previous research (cf., Lawless & Schrader, 2008; Naumann et al., 2008; Salmerón & García, 2011). The results showed that competent readers select and re-visit more pages with task-relevant information. Linear reading thus accounted for an observable behavior which was closely related to the comprehension of digital text. Along with previous findings, this stresses the interpretation that skilled readers, who are able to identify and relate task-relevant statements, select relevant pages and if necessary revisit them in order to establish their interpretation regarding the relation of web page contents. Poor readers, in contrast, might fail to determine and connect the main ideas of various web pages, resulting in the random selection of hyperlinks and poor comprehension of digital text. As shown by the remaining direct effect, though, linear reading is not only associated with digital reading through the selection of appropriate web pages (cf., Salmerón & García, 2011). The direct effect underlines that comprehension processes also induce readers to maintain coherence between text parts (cf., Salmerón et al., 2005, 2010) and to integrate knowledge and experiences in order to create a comprehensive mental representation of the text situation (Kintsch, 1998). These processes might require readers to choose particular strategies of hyperlink selection (e.g., selecting a link according to its semantic relatedness to a reading goal, or personal interests; cf., Salmerón et al., 2005, 2010). Depending on students' prior knowledge and reading skills (Rouet et al., 2011), the choice of strategy can be differently linked to comprehension (Salmeron & Garcia, 2011). Future investigations should therefore examine in more detail how cognitive skills like linear reading are related to various navigation strategies and behaviors.

In the case of students' basic computer skills, the contribution of this ICT-related skill to digital reading performance was completely explained by students' task-relevant navigation behavior. In line with previous research (Goldhammer, Naumann, et al., 2013; Naumann, 2010), students with well-developed basic computer skills were able to find, access, and relocate information in digital environments, indirectly supporting their comprehension of digital text. Although we shed some light on the linkage between basic computer skills and digital reading, there are at least two possible explanations for the found relational patterns, which are not mutually exclusive. Under the perspective of schema theory (cf., Gall & Hannafin, 1994), basic computer skills can be seen as a collection of previously learnt prototypical schemes about the structures and functionalities of digital environments (e.g., publisher information can be found in “About” sections; using back buttons restores the last web pages displayed). On the one hand, applying appropriate schemes could release additional cognitive resources in students, which are then also available for text comprehension processes (cf., Naumann et al., 2008). On the other hand, such schemes could also support the construction of a cognitive map helping students to orientate and fluently locate pages within a hypertext (e.g., Boechler & Dawson, 2005; Waniek et al., 2003). Questions like how basic computer skills support locating relevant information and comprehending digital text should be addressed in further research.

Concerning evaluating online information, we argued that this skill helps students to decide which page contains task-relevant information and where to go next by enabling them to make inferences based on structural and message-based features regarding the usefulness of online information. We also expected this relation to be mediated through students’ task-relevant navigation behavior. The results demonstrated a direct effect of evaluating online information on digital reading. This is in line with findings from qualitative case studies about students’ strategy use in previewing and skimming a page before deciding to act (Coiro et al., 2011; Coiro & Dobler, 2007; Davis & Neitzel 2012). However, there was no indirect effect through students’ task-relevant navigation behavior at any level of linear reading and basic computer skills. This lack of mediation might be due to students’ navigation behavior in two respects. First, one might argue that some of the digital reading items have relieved students of navigational demands by providing a higher degree of guidance in their instruction. The instructions for Example (a) in Figure 1, for instance, hints at the navigational path needed (“Find the page for the Seraing Community Cultural Centre”) compared to the open-ended instructions for Example (b) (“Which sports club would suit […] best?”). Following a recommended path requires one to understand given instructions rather than to decide which information to process next. However, since that explanation would also imply the lack of a direct effect from evaluating online information to digital reading, it needs to be rejected. Second, the outcomes of students’ evaluations of the relevance and credibility of online information could have triggered different navigational strategies and patterns than the ones investigated in this study. Appropriate anticipation of task-relevant content, for instance, might reduce clicks on irrelevant pages rather than increase visits to relevant pages. We tested this suggestion by reanalyzing the prediction of digital reading on the basis of evaluating online information with the number of irrelevant page visits (i.e., the number of all page visits minus the number of relevant page visits) as the mediating variable. The indirect effect was not significant. Therefore, this suggested alternative explanation has to be rejected, too.

In total, the results show that further examination is required with regard to how readers' navigation patterns and associated decisions about processing information in hypertexts might be related. Scanning and critically evaluating the content of web pages might not necessarily direct students to other pages but could affect their processing times for relevant and irrelevant material. Processing relevant information then could be associated with longer processing times. However, when students become aware of irrelevant text material, they might stop information processing, leading to shorter processing times. This relation might also depend on the difficulty and transparency of online texts. The point is that the length of students' visits on web pages can contribute to our understanding of how and under which circumstances readers manage their time, and hence provide further insight into students' cognitive information processing (e.g., Goldhammer, Naumann, Stelter, Tóth, Rölke, & Klieme, 2014; Rouet & Le Bigot, 2007). However, a more careful investigation of the reasons why students navigate digital content in a particular way is also necessary. Reasons for redundant page visits, for instance, could include double-checking information, unintended visits, or even cognitive exhaustion. Therefore, interpretations of click- and time-based events from log-file data need to be validated. Information from self-reports assessed using think-aloud approaches or questionnaires has already been used to supplement log-file records, for instance, in identifying online-specific reading strategies (Coiro et al., 2011; Coiro & Dobler, 2007), or investigating the effects of perceived cognitive load and associated performance differences (e.g., Amadieu, Tricot & Mariné, 2009; Madrid et al., 2009). Additional process indicators such as overall and page-specific processing times, in combination with self-report measures, could be of added value in further elaborations on digital reading skills and should therefore play a stronger role in future research.

4.2 Limitations

The present study contains several limitations which also provide opportunities and challenges for further research. In the following section, we want to especially highlight the problems of (1) the representation of navigation, (2) the impact of other, not considered variables – using the example of prior knowledge, (3) a general but important limitation concerning the interpretation of effect directions, and (4) remarks on the generalizability of the results.

First, the number of relevant page visits and the number of relevant pages visited were used to reflect students' task-relevant navigation, under the assumption that higher scores show a deeper elaboration and consolidation of relevant content. Although both indicators have been shown to be predictive of digital reading and learning with hypertexts (see also Naumann, 2010; Naumann et al., 2007; OECD, 2011), they can raise problems. Regarding the number of relevant page visits, one might consider that higher counts, especially re-visits, could also be a symptom of disorientation or demotivation in students. In this case, a non-linear relationship would describe the relation between navigation and digital reading more accurately: While very low and very high navigation scores would be associated with low scores in digital reading, moderate navigation scores would relate to higher digital reading scores. Figure 5 might also provide an indication of such a curvilinear relationship. The steepness of the relation between higher numbers of relevant page visits and digital reading seems to flatten to a plateau. This form might suggest a continuation as a decrease in digital reading ability with increasing page visits and re-visits. To find such a proposed relationship, however, the PISA items might not provide an information space large enough to show excessive navigation behavior. Regarding the number of pages visited, the indicator is potentially limited in its range since it strongly depends on how many relevant pages are defined for a particular task. Since some tasks only comprise a few relevant pages, correlational patterns can tend to be biased systematically. However, this would be a more serious problem at the item-level than for an average score as used in this study. Regarding both indicators, text selection is just one aspect of task-relevant navigation. To get a comprehensive picture about the relationship between navigation and performance, future studies should integrate several navigation indicators regarding both text selection and features of the navigation path (e.g., degree of coherence, kind and time of backtracks; e.g., Naumann et al., 2007; Salmerón et al., 2005, 2010).

Second, our study only covered a selected set of variables to describe hypertext-specific strategies, skills, or important factors for digital reading (cf., Coiro & Dobler, 2011; Davis & Neitzel, 2012). There are other possible sources of interindividual differences like cognitive style, working memory, or motivational influences – just to name a few. Most apparently, though, the effects of students' prior domain knowledge have to be taken into consideration (Coiro, 2011; Kintsch, 1998). Prior knowledge has been shown to impact readers' decisions on selecting particular hyperlinks (Rouet et al., 2012; Salmerón et al., 2010) and choosing more or less coherent reading paths (Amadieu et al., 2009; Salmerón et al., 2005). Although we cannot rule out effects of differences in students' prior knowledge, these potential effects might be negligible since PISA items were designed to keep the effects of prior knowledge as low as possible by considering many different contents, text formats, reading situations, and reading purposes across tasks (OECD, 2013).

Third, concerning the direction of the investigate effects, causal interpretations of the results cannot be made because of the study's observational design. Strong assumptions, for instance, regarding the temporal order and independence of measures would be necessary to investigate a causal mediation model (cf., Imai, Keele & Tingley, 2010), not feasible in the PISA cross-sectional design. We tried to provide an empirically supported theoretical background and it seems at least plausible that explanatory paths would lead from skills representing the defining components of digital reading to directly observable behavior and related comprehension outcomes.

Fourth, two remaining remarks need to be made on the results' generalizability to different age groups and to the web context. Regarding the first, our study focused on the digital reading skills of 15-year-old adolescents. Adolescence is associated with many cognitive developmental tasks and challenges. Hence, the generalizability of our results to other age groups is restricted. While construct-essential relations, for instance, between linear and digital reading seem to be generally valid (cf., Naumann et al., 2007; Salmerón & García, 2011), other cognitive and meta-cognitive skills, especially those concerning the evaluation of information, appear to develop over time and can differ among age groups (cf., Brand-Gruwel et al., 2009). With respect to different text types and reading situations, the comparison of age-related performance differences in digital reading can be highly relevant for both educators and designers of hypertexts, especially against the backdrop of long life learning. Systematic reviews on age-related differences in digital reading, information processing, and associated comprehension problems as well as the development of age-appropriate assessment tools should therefore be a task for future research. Regarding our study's generalizability to the web context, we used computer-based web simulations to assess digital reading, which surely provide more face validity than a paper-based assessment. Nevertheless, due to practical reasons, the items could not be located within an open web space and therefore might not capture the complexity of real web-based reading. Closely related to this, navigation possibilities were also restricted to the options provided in each item's environment, which might have constrained observable navigation behavior. Further research should strive to cross-validate the digital reading items with other measures of digital reading proficiency.

Conclusions

Information and communication technologies (ICTs) change the way text is presented, which can be challenging for readers due to increased demands with regard to self-directed text selection (e.g., Coiro, 2011; Leu et al., 2004; Rouet, 2006). Our results support this statement by demonstrating specific additional demands for 15-year-old students in the comprehension of digital text accessed on computers: Digital reading is not synonymous with reading linear texts and requires additional skills from students – in particular, skills in dealing with computer environments and in deciding on the usefulness of various information encountered. This study showed that well-developed reading and ICT-related skills are important prerequisites of digital reading by demonstrating unique proportions of variance explained through these components. Good readers with routinized skills in dealing with computers and effective strategies for deciding on the usefulness of web-based information are able to locate, evaluate, and synthesize web-based information. Furthermore, regarding students' linear reading and basic computer skills, the results showed relations to students' actual selection of text. Hypertext readers who already possessed good linear reading skills or could effectively deal with computer interfaces were able to find and fluently re-visit task-relevant pages when constructing their reading path. In other words, if students have difficulties with linear reading or lack basic computer skills, they will struggle to locate and relate relevant information to other information, and are likely to have problems with understanding hypertexts. These findings underline that if we want students to be proficient in reading digital text, we should also support them in mastering skills in dealing with ICTs and in developing effective navigational strategies by providing appropriate learning opportunities and guiding them through challenges (cf., Gil-Flores et al., 2012; Lawless & Schrader, 2008, Leu et al., 2004).

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References

Amadieu, F., Tricot, A., & Mariné, C. (2009). Prior knowledge in learning from a non-linear electronic document: Disorientation and coherence of the reading sequences. *Computers in Human Behavior*, *25*(2), 381–388.

Boechler, P. M. (2001). How spatial is hyperspace? Interacting with hypertext documents: cognitive processes and concepts. *CyberPsychology & Behavior*, *4*, 23–46.

Boechler, P. M., & Dawson, M. R. W. (2005). The effects of spatial layout on relationships between performance, path patterns and mental representation in a hypermedia information search task. *Interactive Technology and Smart Education*, *2*(1), 31–46.

Brand-Gruwel, S., Wopereis, I., & Walraven, A. (2009). A descriptive model of information problem solving while using internet. *Computers & Education*, *53*(4), 1207–1217.

Coiro, J. (2011). Predicting Reading Comprehension on the Internet: Contributions of Offline Reading Skills, Online Reading Skills, and Prior Knowledge. *Journal of Literacy Research : A Publication of the Literacy Research Association*, *43*(4), 352–392.

Coiro, J., Castek, J., & Guzniczak, E. (2011). Uncovering online reading comprehension processes: Two adolescents reading independently and collaboratively on the Internet. *Yearbook of the Literacy Research Association*, *60*, 354–369.

Coiro, J., & Dobler, E. (2007). Exploring the online reading comprehension strategies used by sixth-grade skilled readers to search for and locate information on the Internet. *Reading Research Quarterly*, *42*(2), 214–257.

Davis, D. S., & Neitzel, C. (2012). Collaborative sense-making in print and digital text environments. *Reading and Writing*, *25*(4), 831–856.

Enders, C. K., & Bandalos, D. L. (2001). The relative performance of full information maximum likelihood estimation for missing data in structural equation models. *Structural Equation Modeling*, *8*(3), 430–457.

Feierabend, S., Karg, U., & Rathgeb, T. (2013). *JIM-Studie 2013. Jugend, Information, (Multi-) Media [JIM-Study. Youth, Information, (Multi-) Media]*. Stuttgart: MPFS.

Gall, J., & Hannafin, M. (1994). A framework for the study of hypertext. *Instructional Science*, *22*(3), 207–232.

Gil-Flores, J., Torres-Gordillo, J.-J., & Perera-Rodríguez, V.-H. (2012). The Role of Online Reader Experience in Explaining Students' Performance in Digital Reading. *Computers & Education*, *59*(2), 653–660.

Goldhammer, F., Keßel, Y., & Kröhne, U. (2013, April). *Construct validation of the ICT literacy scale TEO: Task characteristics and process measures*. Presented at the 5th Szeged Workshop on Educational Evaluation (SWEE), Szeged, Hungary.

Goldhammer, F., Naumann, J., & Keßel, Y. (2013). Assessing Individual Differences in Basic Computer Skills: Psychometric Characteristics of an Interactive Performance Measure. *European Journal of Psychological Assessment*, *29*(4), 263–275.

Goldhammer, F., Naumann, J., Stelter, A., Tóth, K., Rölke, H., & Klieme, E. (2014). The Time on Task Effect in Reading and Problem Solving Is Moderated by Task Difficulty and Skill: Insights From a Computer-Based Large-Scale Assessment. *Journal of Educational Psychology*, *106*(3), 608–626.

Graff, M. (2005). Individual differences in hypertext browsing strategies. *Behaviour & Information Technology*, *24*(2), 93–99.

Imai, K., Keele, L., & Tingley, D. (2010). A general approach to causal mediation analysis. *Psychological Methods*, *15*(4), 309–334.

Kintsch, W. (1998). *Comprehension: A Paradigm for Cognition*. Cambridge University Press.

Kline, R. B. (2011). *Principles and practice of structural equation modeling* (3rd ed). New York: Guilford Press.

Kröhne, U., Hahnel, C., Schiepe-Tiska, A., & Goldhammer, F. (2013, August). *Analyzing Mode Effects of PISA Print Reading Including a Comparison of Time-related Information.* Presented at the 15th Biennal Conference of the European Association for Research on Learning and Instruction (EARLI), Munich, Germany.

Lawless, K. A., & Kulikowich, J. M. (1996). Understanding Hypertext Navigation through Cluster Analysis. *Journal of Educational Computing Research*, *14*(4), 385–399.

Lawless, K. A., & Schrader, P. G. (2008). Where do we go now? Understanding research on navigation in complex digital environments. In D. J. Leu & J. Coiro (Eds.), *Handbook of New Literacies* (pp. 267–296). Hillsdale, NJ: Lawrence Erlbaum Associates.

Leu, D. J., Kinzer, C. K., Coiro, J. L., & Cammack, D. W. (2004). Toward a Theory of New Literacies Emerging From the Internet and Other Information and Communication Technologies. In R. B. Ruddell & N. Unrau (Eds.), *Theoretical Models and Processes of Reading* (5th ed., pp. 1568 – 1611). Newark: International Reading Association.

Little, T. D., Cunningham, W. A., Shahar, G., & Widaman, K. F. (2002). To parcel or not to parcel: Exploring the question, weighing the merits. *Structural Equation Modeling*, *9*(2), 151–173.

MacKinnon, D. P. (2008). *Introduction to Statistical Mediation Analysis*. Mahwah, NJ: Erlbaum.

Madden, M., Lenhart, A., Duggan, M., Cortesi, S., & Gasser, U. (2013). *Teens and Technology 2013*. Washington, DC: Pew Research Center's Internet & American Life Project.

Madrid, R. I., Van Oostendorp, H., & Puerta Melguizo, M. C. (2009). The effects of the number of links and navigation support on cognitive load and learning with hypertext: The mediating role of reading order. *Computers in Human Behavior*, *25*(1), 66–75.

Muthén, L. K., & Muthén, B. O. (1998). *Mplus User's Guide* (7th ed). Los Angeles, CA: Muthén & Muthén.

Naumann, J. (2010, May). *Predicting Comprehension of Electronic Reading Tasks: The Impact of Computer Skills and Reading Literacy*. Paper presented at the Annual Conference of the American Educational Research Association (AERA), Denver, CO.

Naumann, J., Richter, T., Christmann, U., & Groeben, N. (2008). Working memory capacity and reading skill moderate the effectiveness of strategy training in learning from hypertext. *Learning and Individual Differences*, *18*(2), 197–213.

Naumann, J., Richter, T., Flender, J., Christmann, U., & Groeben, N. (2007). Signaling in expository hypertexts compensates for deficits in reading skill. *Journal of Educational Psychology*, *99*(4), 791.

Organisation for Economic Co-operation and Development (OECD). (2011). *PISA 2009 Results: Students On Line*. OECD Publishing.

Organisation for Economic Co-operation and Development (OECD). (2013). *PISA 2012 Assessment and Analytical Framework*. OECD Publishing. Retrieved from

Organisation for Economic Co-operation and Development (OECD). (2014). *PISA 2012 Technical Report*. OECD Publishing.

Preacher, K. J., & Kelley, K. (2011). Effect size measures for mediation models: Quantitative strategies for communicating indirect effects. *Psychological Methods*, *16*(2), 93–115.

Prenzel, M., Sälzer, C., Klieme, E., & Köller, O. (2013). *PISA 2012. Fortschritte und Herausforderungen in Deutschland [PISA 2012. Progress and challenges in Germany]*. Münster: Waxmann.

Rieh, S. Y. (2002). Judgment of information quality and cognitive authority in the Web. *Journal of the American Society for Information Science and Technology*, *53*(2), 145–161.

Revelle, W., & Zinbarg, R. E. (2009). Coefficients alpha, beta, omega, and the GBL: Comments on Sijtsma. *Psychometrika*, *74*(1), 145-154.

Rouet, J.-F. (2006). *The skills of document use: from text comprehension to Web-based learning*. Mahwah, NJ: Erlbaum.

Rouet, J.-F., & Britt, M. A. (2011). Relevance processes in multiple document comprehension. In M. T. McCrudden, J. Magliano, & G. Schraw (Eds.), *Text relevance and learning from text* (pp. 19–52). Greenwich, CT: Information Age Publishing.

Rouet, J.-F., & Le Bigot, L. (2007). Effects of academic training on metatextual knowledge and hypertext navigation. *Metacognition and Learning*, *2*(2-3), 157–168.

Rouet, J.-F., Ros, C., Goumi, A., Macedo-Rouet, M., & Dinet, J. (2011). The influence of surface and deep cues on primary and secondary school students' assessment of relevance in Web menus. *Learning and Instruction*, *21*(2), 205–219.

Salmerón, L., Cañas, J. J., Kintsch, W., & Fajardo, I. (2005). Reading Strategies and Hypertext Comprehension. *Discourse Processes*, *40*(3), 171–191.

Salmerón, L., & García, V. (2011). Reading skills and children's navigation strategies in hypertext. *Computers in Human Behavior*, *27*(3), 1143–1151.

Salmerón, L., Kintsch, W., & Kintsch, E. (2010). Self-regulation and link selection in hypertext. *Discourse Processes*, *47*, 175–211.

van Buuren, S. (2012). *Flexible imputation of missing data*. Boca Raton, FL: CRC Press.

Walraven, A., Brand-Gruwel, S., & Boshuizen, H. P. A. (2009). How students evaluate information and sources when searching the World Wide Web for information. *Computers & Education*, *52*(1), 234–246.

Waniek, J., Brunstein, A., Naumann, A., & Krems, J. F. (2003). Interaction between text structure representation and situation model in hypertext reading. *Swiss Journal of Psychology*, *62*(2), 103.

Appendix A

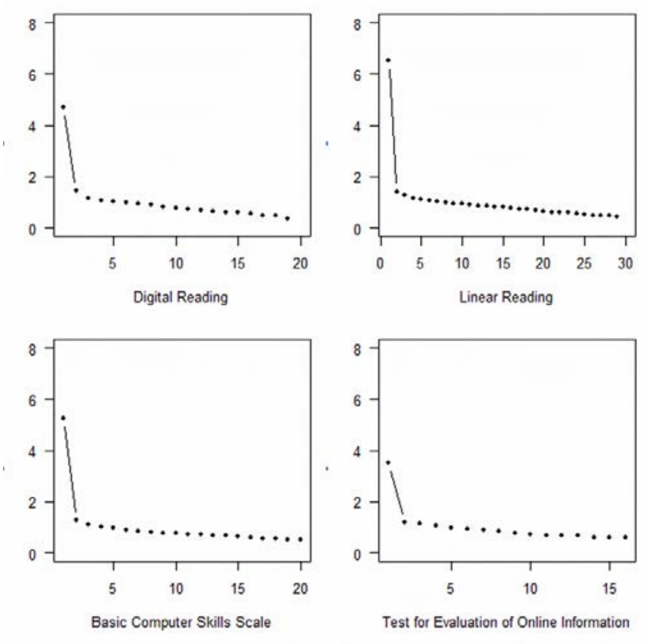

Figure A. Scree plots of the scales for digital reading (upper left), linear reading (upper right), basic computer skills (lower left), and evaluating online information (lower right). Course of the eigenvalues based on the matrix of inter-item correlations (Kendalls' correlation coefficients).

Appendix B

Table B

Correlations among and between item parcels, the number of relevant page visits, and the number of relevant pages visited

Parcel	DR 01		DR 02		DR 03		DR 04		DR 05		DR 06		LR 01		LR 02		LR 03		LR 04	
	Est	*p*	*Est*	*p*	*Est*	*p*	*Est*	*p*	*Est*	*p*	*Est*	*p*	*Est*	*p*	*Est*	*p*	*Est*	*p*	*Est*	*p*
DR 02	.44	<.001																		
DR 03	.53	<.001	.55	<.001																
DR 04	.40	<.001	.44	<.001	.50	<.001														
DR 05	.34	<.001	.37	<.001	.44	<.001	.50	<.001												
DR 06	.34	<.001	.40	<.001	.46	<.001	.48	<.001	.42	<.001										
LR 01	.32	<.001	.29	<.001	.35	<.001	.42	<.001	.40	<.001	.34	<.001								
LR 02	.44	<.001	.34	<.001	.31	<.001	.40	<.001	.36	<.001	.33	<.001	.57	<.001						
LR 03	.32	<.001	.32	<.001	.34	<.001	.32	<.001	.32	<.001	.26	<.001	.51	<.001	.64	<.001				
LR 04	.30	<.001	.29	<.001	.25	<.001	.23	<.001	.29	<.001	.25	<.001	.50	<.001	.59	<.001	.49	<.001		
LR 05	.52	<.001	.40	<.001	.38	<.001	.49	<.001	.41	<.001	.38	<.001	.54	<.001	.64	<.001	.54	<.001	.59	<.001
BCS 01	.42	<.001	.35	<.001	.40	<.001	.34	<.001	.35	<.001	.40	<.001	.36	<.001	.40	<.001	.43	<.001	.30	<.001
BCS 02	.30	<.001	.33	<.001	.28	<.001	.31	<.001	.28	<.001	.34	<.001	.34	<.001	.32	<.001	.35	<.001	.20	<.001
BCS 03	.32	<.001	.42	<.001	.35	<.001	.39	<.001	.42	<.001	.39	<.001	.36	<.001	.45	<.001	.42	<.001	.29	<.001
BCS 04	.30	<.001	.38	<.001	.37	<.001	.41	<.001	.33	<.001	.37	<.001	.38	<.001	.42	<.001	.38	<.001	.28	<.001
BCS 05	.36	<.001	.33	<.001	.42	<.001	.38	<.001	.46	<.001	.37	<.001	.39	<.001	.42	<.001	.38	<.001	.24	<.001
EOI 01	.34	<.001	.37	<.001	.40	<.001	.34	<.001	.37	<.001	.35	<.001	.37	<.001	.42	<.001	.38	<.001	.28	<.001
EOI 02	.31	<.001	.15	.030	.30	<.001	.27	<.001	.25	<.001	.36	<.001	.27	<.001	.33	<.001	.29	<.001	.25	<.001
EOI 03	.41	<.001	.28	<.001	.35	<.001	.30	<.001	.25	<.001	.29	<.001	.33	<.001	.38	<.001	.36	<.001	.19	<.001
EOI 04	.39	<.001	.27	<.001	.38	<.001	.38	<.001	.28	<.001	.24	<.001	.34	<.001	.41	<.001	.38	<.001	.26	<.001
NAV 1	.46	<.001	.54	<.001	.62	<.001	.61	<.001	.55	<.001	.42	<.001	.36	<.001	.40	<.001	.32	<.001	.28	<.001
NAV 2	.47	<.001	.55	<.001	.61	<.001	.60	<.001	.59	<.001	.50	<.001	.35	<.001	.40	<.001	.30	<.001	.30	<.001

Table B continuation

Correlations among and between item parcels, the number of relevant page visits, and the number of relevant pages visited

Parcel	LR 05		BCS 01		BCS 02		BCS 03		BCS 04		BCS 05		EOI 01		EOI 02		EOI 03		EOI 04		NAV 1	
	Est	*p*	*Est*	*p*	*Est*	*p*	*Est*	*p*	*Est*	*p*	*Est*	*p*	*Est*	*p*	*Est*	*p*	*Est*	*p*	*Est*	*p*	*Est*	*p*
BCS 01	.46	<.001																				
BCS 02	.30	<.001	.46	<.001																		
BCS 03	.43	<.001	.57	<.001	.48	<.001																
BCS 04	.41	<.001	.57	<.001	.50	<.001	.54	<.001														
BCS 05	.37	<.001	.54	<.001	.50	<.001	.57	<.001	.55	<.001												
EOI 01	.43	<.001	.39	<.001	.32	<.001	.41	<.001	.40	<.001	.42	<.001										
EOI 02	.35	<.001	.42	<.001	.30	<.001	.41	<.001	.37	<.001	.36	<.001	.46	<.001								
EOI 03	.36	<.001	.33	<.001	.33	<.001	.35	<.001	.36	<.001	.38	<.001	.47	<.001	.38	<.001						
EOI 04	.41	<.001	.37	<.001	.31	<.001	.31	<.001	.33	<.001	.34	<.001	.48	<.001	.35	<.001	.44	<.001				
NAV 1	.43	<.001	.39	<.001	.30	<.001	.38	<.001	.38	<.001	.38	<.001	.35	<.001	.25	<.001	.25	<.001	.34	<.001		
NAV 2	.41	<.001	.44	<.001	.31	<.001	.40	<.001	.39	<.001	.42	<.001	.34	<.001	.27	<.001	.23	<.001	.33	<.001	.91	<.001

Notes. DR = Digital reading. LR = Linear reading. BCS = Basic computer skills. EOI = Evaluating online information. NAV 1 = Number of relevant page visits. NAV 2 = Number of relevant pages visited.

Appendix C

Table C.1

Descriptive statistics about the number of relevant pages visited and correlations with the latent variables and the number of relevant page visits

	M	*SD*	*Min*	*Max*	DR	LR	BCS	EOI	NAV1
Relevant pages visited	3.32	1.25	1.00	6.00	.82	.51	.55	.47	.91

Note. DR = Digital reading. LR = Linear reading. BCS = Basic computer skills. EOI = Evaluating online information. NAV1 = Relevant page visits and revisits. All correlations were significant at $p < .001$.

Table C.2

Results of the regression of digital reading on the number of relevant pages visited

Predictor	$\hat{\beta}$	*SE*	*p*	R^2
Relevant pages visited	.84	0.03	<.001	.71

Notes. χ^2 (14) = 43.69, p = <.001; RMSEA = .07, CFI = .96, TLI =. 94, SRMR = .09.

Table C.3

Summary of the results of the prediction of digital reading by linear reading, basic computer skills, and evaluating online information through the number of relevant pages visited as mediator

Dependent variable	Independent variable	Estimate	*SE*	*p*	κ
Digital Reading	Relevant pages accessed	.56	.05	<.001	
Relevant pages accessed	Linear reading	.23	.09	.010	
	Basic computer skill	.38	.09	<.001	
	Evaluating online information	.02	.11	.878	
Direct effects					
Digital Reading	Linear reading	.19	.07	.011	
	Basic computer skill	.12	.08	.167	
	Evaluating online information	.22	.09	.016	
Indirect effects through relevant pages accessed					
Digital Reading	Linear reading	.13	.05	.013	.12
	Basic computer skill	.21	.06	<.001	.26
	Evaluating online information	.01	.06	.878	-

Note. Standardized coefficients. R^2 = .83. Model fit: χ^2 (180) = 249.27, $p < .001$; RMSEA = .02, CFI = .99, TLI =. 98, SRMR = .04.

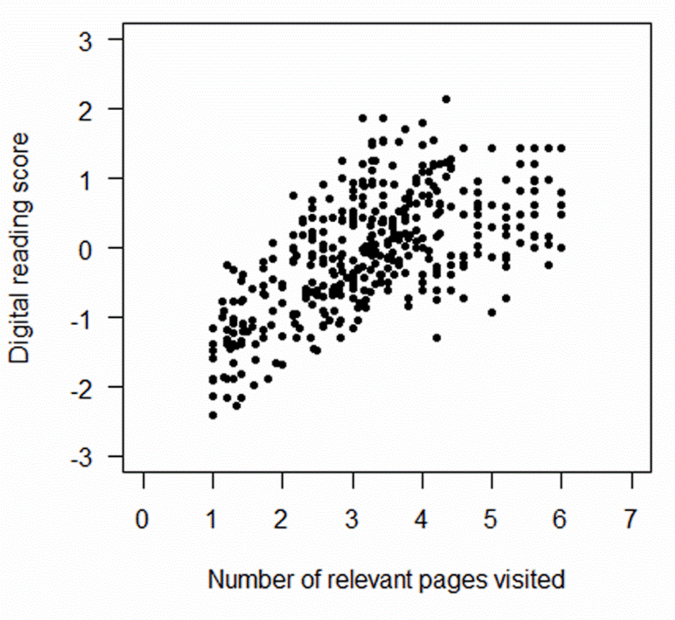

Figure C.1. Scatter plot of students' digital reading performance and the number of relevant pages visited.

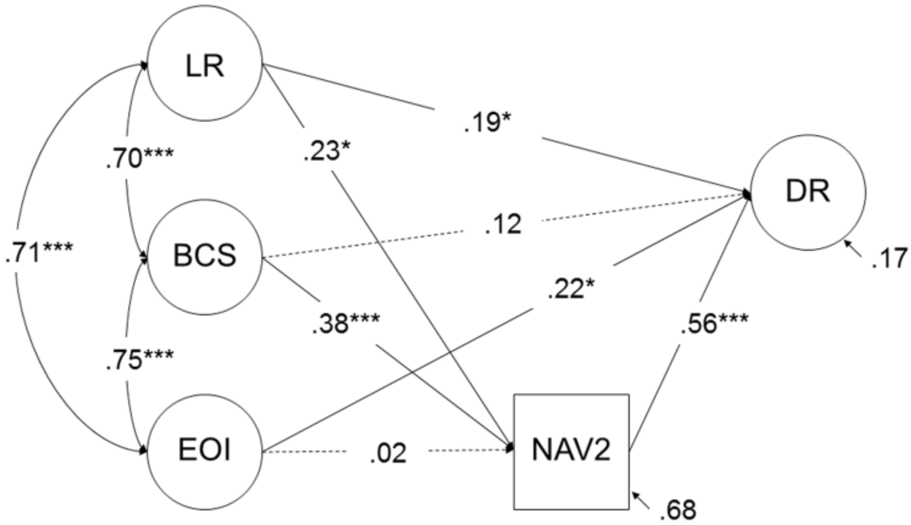

Figure C.2. Estimated mediation model with standardized regression coefficients. LR = Linear reading. BCS = Basic computer skills. EOI = Evaluating online information. NAV2 = Number of relevant pages visited. DR = Digital Reading. Solid arrows describe significant paths; dashed arrows describe non-significant paths.

Appendix D

For the illustration of items from the Basic Computer Skill Scale and the Test for Evaluation of Online Information, screenshots of similar items were prepared using text and artwork from the following sources.

References for Figure 2:

Butterfly. (2015, July 28). In Wikipedia, The Free Encyclopedia. Retrieved 15:27, July 30, 2015, from https://en.wikipedia.org/w/index.php?title=Butterfly&oldid=673503162 - Licensed under CC BY-SA 3.0 via Wikimedia Commons http://creativecommons.org/licenses/by-sa/3.0/

Apel, M. (2012, May 20). Anthocharis cardamines female. Own work. Licensed under CC BY 3.0 via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Anthocharis_cardamines_female_MichaD.jpg#/media/File:Anthocharis_cardamines_female_MichaD.jpg

References for Figure 3:

Paragliding. (2015, July 28). In Wikipedia, The Free Encyclopedia. Retrieved 15:25, July 30, 2015, from https://en.wikipedia.org/w/index.php?title=Paragliding&oldid=673479869 - Licensed under CC BY-SA 3.0 via Wikimedia Commons http://creativecommons.org/licenses/by-sa/3.0/

Pastelitodepapa (2012, May 23). Paraglider ridge soaring at Torrey Pines. Own work. Licensed under CC BY-SA 3.0 via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Paraglider_ridge_soaring_at_Torrey_Pines.jpg#/media/File:Paraglider_ridge_soaring_at_Torrey_Pines.jpg

STUDY 3

Publication Note

Hahnel, C., Goldhammer, F., Kröhne, U., & Naumann, J. (under review, *Computers in Human Behavior*). The role of reading for the evaluation of online information gathered from search engine environments.

The role of reading for the evaluation of online information gathered from search engine environments

A critical evaluation to find useful information is essential when doing a web search. In this study, we investigated this evaluation skill of secondary school students, based on their behavior in selecting hyperlinks from a search engine result page (SERP). To clarify the role of reading for the evaluation of online information, we additionally assessed students' individual reading skills on word, sentence, and text level. Data of 416 15-year-old students participating in a computer based German add-on study to the *Programme for International Student Assessment* (PISA) in 2012 were investigated. Using generalized linear mixed models (GLMMs), effects of reading skills on the skill to evaluate online information were found. These effects were influenced by the similarity of SERP hyperlinks in relevance and students' navigation to subsequent SERPs or websites. The results are interpreted as skilled readers are able to allocate their cognitive resources more efficiently than less skilled readers when evaluating online information. Implications are discussed in terms of underlying cognitive processes in making web search decisions.

Search engines have become a ubiquitous tool in using the World Wide Web. As a broad information resource, they provide easy access for web users who seek information for any purpose, such as educational, occupational, and private. Search engine environments are frequently used by secondary school students (e.g., Feierabend, Karg & Rathgeb, 2013; OECD [Organisation for Economic Co-operation and Development], 2011).Yet, they reveal a vast amount of information considerably varying in relevance and quality. A critical evaluation of information in terms of relevance and credibility is crucial since an incorrect use of information can result in inappropriate decisions and serious consequences (Brand-Gruwel & Stadtler, 2011). Many students, though, show difficulties in selecting adequate online information (e.g., Brand-Gruwel, Wopereis & Walraven, 2009; Lucassen, Muilwijk, Noordzij & Schraagen, 2013; Walraven, Brand-Gruwel & Boshuizen, 2008).

Evaluating the appropriateness of information for solving a search task requires information to be identified and comprehended. Students and even adults differ in their reading proficiency on word, sentence, and text level (e.g., Perfetti 2007; Sabatini, 2015) which raises questions of whether and how reading skills affect their selection of online information. Therefore, the present study seeks to shed light on the role of reading as a conditioning factor of success when evaluating information from search engine result pages (SERPs). We investigated whether or not hierarchically related reading skills on word, sentence, and text level affect students' evaluation of online information. Furthermore, we examined if these reading effects were influenced by characteristics of SERP hyperlinks and individual user behavior of students. As characteristic of SERP hyperlinks, we considered how similar they were in terms of their relevance to a search task. As individual user behavior, students' navigation behavior to other SERPs as well as to websites connected to SERP hyperlinks was investigated.

1.1 Reading and processing web search information

An information-based web search usually starts by identifying a gap of knowledge (cf. Brand-Gruwel et al., 2009; Gerjets, Kammerer & Werner, 2011). Web users define a search task, verbalize a query, and enter it into a chosen search engine like Google. A SERP appears that lists several text abstracts with hyperlinks leading to websites of potential interest. Search engines offer a first classification but it is people who need to decide if the listed information meets the requirements of their search task. Therefore, web users are assumed to use criteria of information relevance and credibility affecting their processing and efforts in evaluating online information (Flanagin & Metzger, 2007; Metzger, 2007; Hilligoss & Rieh, 2008; Rieh, 2002). According to dual processing theory (Evans, 2008; Wirth, Böcking, Karnowski, & von Pape, 2007), web users will evaluate SERP information either heuristically or systematically. Systematic processing means web users perform an extensive evaluation of collected information, based on various characteristics (e.g., topic relevance, trustworthiness, completeness; Salmerón, Kammerer & García-Carrión, 2013). These processes are slow and deliberate, making them cognitively demanding. Especially when dealing with the "information flood" provided by search engines, mental costs of thorough search might be severe (Rieh, Kim, & Markey, 2012). In contrast, heuristic processing is fast and automatic and demands fewer cognitive resources to operate (Gigerenzer & Gaissmaier, 2011), but only focuses on limited characteristics of existing information (e.g., does information confirms one's expectation; Metzger, Flanagin, & Medders, 2010) that might be insufficient for adequate information selection.

When evaluating online information, reading is the essential component in receiving and processing written information. While reading, individuals are assumed to actively construct a mental representation that integrates a text representation of word structures and propositional meaning with one's general knowledge (Kintsch, 1998; Perfetti & Stafura, 2014; Rouet, 2006). This process is supposed to be semi-hierarchically organized on word, sentence, and text level (e.g., Hamilton, Freed & Long, 2013; Perfetti & Stafura, 2014; Richter, Isberner, Naumann & Kutzner, 2012). For experienced readers, basic reading activities like lexical access and propositional integration occur automatically (Perfetti, 2007; Samuels & Flor, 1997; Walczyk, 2000). Nevertheless, controlled processes (e.g., reflection, evaluation of text) are necessary for deep elaboration of text meaning.

In web search, SERP information is usually presented in fragmented hyperlink abstracts, requiring readers to make selections based on sparse information. If web information is interpreted improperly, web users will come to incorrect conclusions in their evaluations, among other consequences. Since verbal SERP information is often just skimmed for keywords and phrases (Coiro & Dobler, 2007; Salmerón, Naumann, García & Fajardo, 2016), skills in retrieving meaning and comprehension are indispensable. For example, Rouet, Ros, Goumi, Macedo-Rouet and Dinet (2011) found that students matching for exact words selected more irrelevant link titles than students using semantic cues. Using surface cues like in word matching might spare cognitive resources, but it is often not an appropriate heuristic strategy for assessing the relevance of information.

1.2 Influences of the information basis

The way of individual information processing can be influenced by semantic and structural characteristics of information. Web users, for example, invested more time and cognitive resources in the evaluation of online information when heuristic expectations about hyperlinks concerning their order (Pan, Hembrooke, Joachims, Lorigo, Gay & Granka, 2007) or presentation format (Kammerer & Gerjets, 2014) were not met (Metzger et al., 2010). According to current models of web navigation (e.g., CoLiDeS+; Juvina & van Oostendorp, 2008), hyperlink selection is driven by the semantic similarity – or information scent – between presented information and a pursued search task (Blackmon, 2012). Information scent is assumed to be delivered by the hyperlink's abstract or contextual cues like page arrangements. Empirically, web users selected nearly perfectly adequate hyperlinks from websites if information was semantically close to a search task

(Blackmon, 2012). Since proficient readers are able to retrieve meaning accurately, quickly and with lower mental effort (Samuels & Flor, 1997; Walczyk, 2000), they might have an advantage over less skilled readers in identifying relevant information. This could be especially the case when the task-specific relevance of information is comparably easy to identify and web users are not in need to extensively allocate their cognitive resources. For example, when seeking for information about migraine to prepare a talk in biology class, the relevance of advertisements for new pharmaceuticals would be easier to distinguish as irrelevant material than news reports of medicals journals. Although both information sources share the same keywords ("migraine"), the hyperlink context informs the web user about the proximity to the search goal. In case that all hyperlinks are semantically close to a search task, web users will rather take other criteria into account to judge the usefulness of particular information sources (e.g., layout cues, prior content knowledge, or personal experiences to determine if information from Wikipedia is as good as from medical journals for completing a specific search tasks).

From a structural perspective, readers create actively their own information basis by deciding which information to read and which not. The selection of text (fragments) including page transitions in hypertext is often connoted with the concept of navigation (Lawless & Schrader, 2008). For digital text in general, students' navigation behavior was found to be an important predictor of their comprehension (e.g., Hahnel, Goldhammer, Naumann & Kröhne, 2016; Naumann, Richter, Christmann & Groeben, 2008; Salmerón, Cañas, Kintsch & Farjado, 2005). For web search in particular, though, students often look intensively at the first three search results on a SERP, but mainly ignore the rest (Pan et al., 2007), and visits over and above the first result page are often not even performed (Van Deursen & van Dijk, 2009). When using a search engine, students can navigate from a SERP to other ones or click on SERP hyperlinks to visit the websites connected. Navigation to other SERPs can be required when no suitable information is found on a previous SERP and a search query is not reformulated. Navigation to websites of SERP hyperlinks, in contrast, might be needed for further inspection of information confirming or rejecting its relevance. However, enriching the information basis of text generally increases the complexity in reading processes and draws upon limited cognitive resources (cf. DeStefano & LeFevre, 2007; Hamilton et al., 2013; Liu, Chin, Payne, Fu, Morrow & Stine-Morrow, 2016; Perfetti & Stafura, 2014). Therefore, skilled readers might have an advantage over poor readers when more information is encountered.

1.3 Study rationale

This study aims at investigating how individual differences in reading skills on word, sentence, and text level affect the selection of information from SERPs and whether these relations are influenced by semantic and structural characteristic of information. Web users might identify relevant web information by just scanning links for semantically relevant keywords, but also by comparing and weighting the content of several hyperlink entries against each other. Therefore, we expected that reading skills on word, sentence, and text level predict positively information selection from SERPs (H1). Web users are likely to select information that is semantically close to their search task. Compared to poor readers, though, proficient readers might make better hyperlink selections because they invest less cognitive resources in text processing. This might be especially true when relevant hyperlinks are easily to distinguish from non-relevant hyperlinks. Therefore, positive effects of reading skills on evaluating online information should be more pronounced, the more the SERP hyperlink abstracts vary in their relevance to a search task (H2). Web users' navigation to other pages determines the information basis for their selection of online information. Examining hyperlinks by checking other available alternatives (i.e., navigation to other SERPs) or verifying its fit to a search task (i.e., navigation to SERP websites) should positively predict students' evaluation of online information (H3). Since students encounter new written information through navigation, though, skilled readers should be at advantage over less skilled readers since they can process text information more efficiently. Therefore, we expected the relation of reading skills and evaluating online to increase when students navigate to other SERPs or SERP websites (H4).

Method

2.1 Sample

The analyzed data originated from a subsample of the *Programme for International Student Assessment* 2012 (PISA; OECD, 2013). Participating students were randomly sampled from a systematic sample of schools having 15-year-old students (details see OECD, 2014). For hypotheses testing, the data of 416 German students from 75 schools were considered (45.19% female, M_{age} = 15.84, SD_{age} = 0.29) who participated in PISA 2012 as well as in a national add-on study on computer based assessment (CBA).

2.2 Measures

2.2.1 Evaluating online information

The 16 items of the Test for the Evaluation of Online Information (TEO; Pfaff & Goldhammer, 2010) were used to measure individual skill in evaluating online information. The items simulate a search task together with a corresponding SERP (Figure 1). Search tasks vary from rather information-oriented (e.g., preparing a talk on autoimmune diseases for biology class) to problem-focused contents (e.g., seeking information about how to change a bicycle chain; see Appendix). The topics were chosen assuming students to have little or no prior knowledge about the content. Four TEO items displayed one SERP containing six hyperlinks; another four items provided an additional second SERP containing ten links in total. The remaining eight items consisted of a SERP of three or five hyperlinks leading to subsequent websites. The websites were static (e.g., hyperlinks, buttons, or menu entries were inactive). Task-specific and general instructions were presented on the left screen side.

2.2.1.1 Dependent variable. Students were requested to select the most informative and credible SERP hyperlink given a particular search task. They were asked to work as accurately and quickly as possible. Students' responses were scored by a pre-defined dichotomous scoring scheme (incorrect vs. correct). The dichotomous responses served as dependent variable to model the students' probability of successful item solution (see section 2.4 Data Analysis).

2.2.1.2 SERP characteristics. In order to determine to what extent SERP hyperlinks differ in their relevance to the search task, we built the indicator 'variability in relevance' as independent item variable. We asked 7 PhD students (85.71% female; $M_{age} = 29.43$, $SD_{age} = 3.41$) with a background in computer based assessment to rate each of the in total 96 hyperlinks. On a 4-point Likert scale, they were asked to rate how relevant a particular hyperlink is for a given search task (0 = 'not at all relevant' to 3 = 'absolutely relevant'). Kendall's coefficient of concordance for ordinal data revealed an acceptable interrater agreement ($W_t = .69$). The ratings were averaged across raters for each hyperlink and their variances were determined for each item. A high variability in an item points out that hyperlinks are highly distinguishable in relevance and heterogeneous in their semantic fit to a search task (*z*-standardized; *Min* = -1.91, *Max* = 1.86; Appendix).

2.2.1.3 Navigation behavior. Dichotomous indicators of navigation behavior reflected whether or not students performed a page transition at least once – either a transition to a second SERP or to SERP link websites. Therefore, they could only be derived for the four items containing two SERPs as well as the 8 items containing one SERP with websites (Appendix).

2.2.2 Reading skills on word and sentence level

To measure reading skills on word and sentence level, two subscales of the ProDi-L reading inventory were used (Richter et al., 2012). A lexical decision task assessed students' word recognition, asking whether a presented letter combination was a word or not (16 words vs. 16 non-words). The length of the stimulus material was about 3 to 10 letters and 1 to 3 syllables. Words were nouns varying in type, frequency, regularity, and amount of orthographic neighbors. Non-words were created to vary orthographically and phonologically (e.g., changing the onset, "bame" instead of "name"; cf. Balota, Cortese, Sergent-Marshall & Yap, 2004). Using a sentence verification task, semantic integration was assessed in students. They were asked if a presented sentence was either true or false (12 true vs. 12 false sentences; e.g., "Sugar is sweet", "A cactus is a little furry animal"). Stimuli varied in their number of propositions and semantic abstractness. The sentence length varied between 16 to 61 characters and 1 to 3 propositions. Items of both tests were presented successively on a laptop screen. Students were asked to respond as accurately

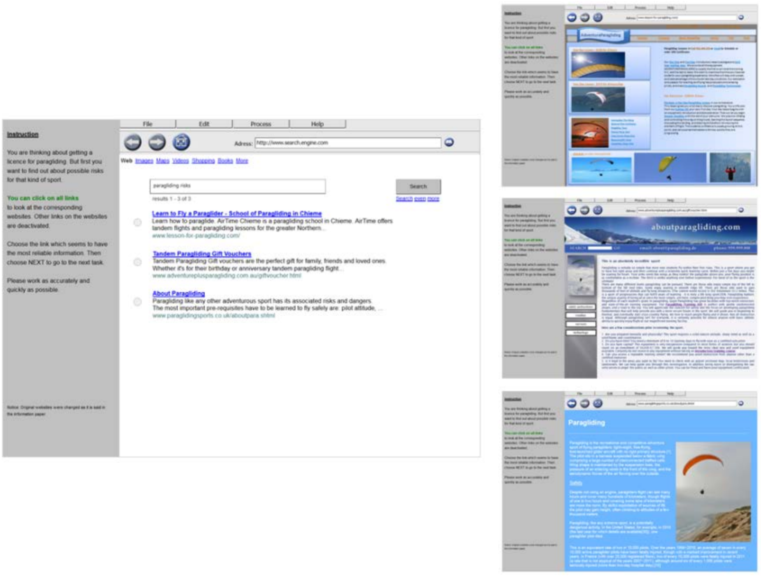

Figure 1. Screenshot of a TEO item example with active hyperlinks. The first page is a search engine result page (SERP) for the topic "paragliding" with three search results (left). If one of the three hyperlinks is clicked, students will be lead to the corresponding connected website (right). Backtracking to the SERP was possible.

and quickly as possible. Their dichotomously coded responses (correct vs. incorrect) as well as their reaction times were collected.

The ProDi-L reading tests were originally developed for primary school children. To have skill indicators that comprise both students' response accuracy and processing speed, drift rates were derived from diffusion models as skill indicators (Ratcliff, Gomez & McKoon, 2004; Schroeder, 2011). Diffusion models are based on the assumption that a decision results from an accumulation process of information over time. To decide between two response alternatives, information about a presented stimulus is collected until a defined decision criterion is reached. As a consequence, associated response behavior is shown (e.g., a student recognizes "hedgehog" as a word and responds with "word"). The efficiency of the information accumulation process is the drift rate. Individuals with higher drift rates show faster and a more accurate decision behavior than individuals with lower drift rates (Voss, Rothermund & Voss, 2004). Using the software *fast-dm* (Voss & Voss, 2007), the drift rates for students' word recognition and semantic integration were estimated. High scores reflected that students were more accurate and faster in retrieving words from their mental lexicon and evaluating the semantic context of short statements, respectively.

2.2.3 Reading skills on text level

For the assessment of text level reading skills, two reading clusters from PISA 2009 were used to measure reading comprehension. PISA reading tasks are organized into units, that is, a text with three to five subsequent items. Four reading units are summarized into one cluster. The unit texts are designed to take several formats (e.g., continuous and non-continuous text) and types (e.g., description, narration, argumentation), and to cover several reading situations (e.g., personal, public, educational). The items request explicit and implicit information of the unit text, and can also require the student to reflect on a text. Item formats included multiple choice as well as open response formats. Text responses were coded according to standardized coding guidelines by trained and supervised coders of the Data Processing and Research Center (DPC) of the International Association for the Evaluation of Educational Achievement (IEA). Released items can be retrieved from the OECD website (http://www.oecd.org/pisa/38709396.pdf).

Note that for another study on equivalence between computer and paper based assessment, the reading clusters were administered on computer and paper in a randomized within- and between group balanced design. Item responses were examined for differences between these modes (Kröhne, Hahnel, Schiepe-Tiska & Goldhammer, 2013). Only items that did not show statistically significant differences in difficulty were regarded for further analyses. Therefore, responses to 18 out of 29 items were used in this study. WLE scores were derived from a partial credit item response model (Masters, 2010; scaling sample N = 880; estimated with *TAM*, Kiefer, Robitzsch & Wu, 2016) and served as ability estimates of students' reading comprehension. High scores reflected that students do well in comprehending texts. Reliability was acceptable (WLE reliability = .69, Cronbach's α = .83).

2.3 Procedure

The data originated from the German CBA add-on study that examined computer based assessment in the context of PISA (cf. Hahnel et al., 2016). This study took place a week after the PISA 2012 main study and was predominantly computer based. Trained test administrators tested about 14 students per school (data of 888 students was collected in total). All students were asked to complete one reading cluster within the first 30 minutes. After that, they either received (1) the TEO and the tests on word recognition and semantic integration, or (2) a second reading cluster and other tests. Only the former condition included the assessment of all variables investigated. Students were randomly assigned to all conditions. Comprehensive tutorials on the structure and functionalities of item surfaces and practice tasks were given for each test.

2.4 Data Analysis

Generalized linear mixed models (GLMM; De Boeck et al., 2011) were used for statistical analyses. These models assume that the probability of success can be expressed as a linear combination of fixed and random effects for predictor variables using a logit link function. Fixed effects do not differ for the observed units (e.g., students, items); random effects allow for variability across them. In this study, the logit of the probability P that a student correctly solves a TEO evaluation task was investigated, regarding the nested structure of items ($i = 1, \ldots, I$) in students ($j = 1, \ldots, N$) and schools ($k = 1, \ldots, K$). A baseline model was specified by

$$\operatorname{logit}(P_{ijk}) = \beta_i + \theta_j + \theta_k \,, \qquad (1)$$

where success in the TEO evaluation tasks is described as linear combination of the item easiness (fixed effect β_i), a student's skill in evaluating online information (random intercept θ_j) and a school's performance level (random intercept θ_k). This model was extended for hypothesis testing. First, the impact of the reading skills ($p = 1, \dots, 3$) on the evaluation of online information was modeled as

$$\operatorname{logit}(P_{ijk}) = \beta_i + \theta_j + \theta_k + \sum_{p=1}^{P} \zeta_p Z_{(j,k)p} , \tag{2}$$

where ζ_p is the fixed effect of individual reading skills $Z_{(j,k)p}$ in word recognition ($p = 1$), semantic integration ($p = 2$), and reading comprehension ($p = 3$). Since reading skills are interrelated (e.g., Perfetti & Stafura, 2014), we examined models with Z_1, Z_2 and Z_3 separately as well as combined. Second, to investigate how the item variable 'variability in relevance' (X_i) affects the effects of reading on evaluating online information, an interaction term was added, resulting in

$$\operatorname{logit}(P_{ijk}) = \beta_i + \theta_j + \theta_k + \sum_{p=1}^{P} \zeta_p Z_{(j,k)p} + \sum_{p=1}^{P} \zeta_p^* Z_{(j,k)p} X_i . \tag{3}$$

The coefficient ζ_p represents now the effects of reading in items with an average variability level in relevance, whereas ζ_p^* reflects how this effect changes when the variability in relevance increases. Note that a main effect of 'variability in relevance' is integrated in the item easiness parameters that are specified as fixed effects. Finally, the model was modified a last time to include the indicator of students' navigation behavior ($W_{(i,j,k)}$) to examine effects of navigation. Separate models for items containing two SERPs and items containing a SERP with websites were estimated since the interpretation of the indicators differ between types of navigation. The resulting model includes the effect of navigation on evaluating online information (ω) and how the effect of the reading skills changes when students navigate between pages (ζ_p^*):

$$\operatorname{logit}(P_{ijk}) = \beta_i + \theta_j + \theta_k + \sum_{p=1}^{P} \zeta_p Z_{(j,k)p} + \omega W_{(i,j,k)} + \sum_{p=1}^{P} \zeta_p^* Z_{(j,k)p} W_{(i,j,k)} . \tag{4}$$

All analyses were carried out in *R 3.2.4* (R Core Team, 2016). For the estimation of GLMMs, the *R* package *lme4* was used (Bates, Mächler, Bolker & Walker, 2015; De Boeck et al., 2011). The hypotheses were tested one-sided at a significance level of 5%. Continuous variables were *z*-standardized. Regression coefficients can be interpreted as predicted changes in log odds for responding correctly if one predictor increases by one standard deviation.

Results

Estimating the baseline model showed that students vary in their skill to evaluate online information on an individual level ($Var(\theta_j) = 0.38$) as well as school level ($Var(\theta_k) = 0.32$). The estimated item easiness is presented in the Appendix for each item. Note that we refrain from reporting these parameters for all following models.

Concerning the impact of word, sentence, and text level reading skills on evaluating online information, the results of the models including the predictors separately and combined are presented in Table 1. They show that the separate predictors contributed significantly and positively to predict students' evaluation skill. Students selected rather relevant and credible hyperlinks when they were skilled in recognizing words, verifying semantic content of short statements, and comprehending texts. Although all reading skill components were positively correlated (word recognition - semantic integration: $r = .32$, $p < .001$; word recognition - reading comprehension: $r = .40$, $p < .001$; semantic integration - reading comprehension: $r = .38$, $p < .001$), both semantic integration and reading comprehension remained to be predictive in the combined model. The amount of variance explained was moderate in models including reading comprehension as predictor (R^2 in Table 1).

To investigate how the similarity of SERP hyperlinks in relevance affect the association of reading skills and evaluating online information, models containing the item variable 'variability in relevance' were estimated. Table 2 shows the results. The main effects of all reading skills remained, given an average level of variability in relevance. The interaction effects show that only the effect of reading comprehension on evaluating online information rose with the an increasing variability of relevance in SERP hyperlinks. This was not true for the effects of reading skills on word and sentence level, neither in the separate models nor in the combined model.

Concerning the influences of navigation, the effects of reading skills were examined for evaluation items containing two SERPs and, respectively, one SERP with websites. For the four items with two SERPs, a descriptive analysis of students' navigation behavior revealed that about half the students did not navigate at all in this condition (about 46% to

68% per item). Table 3 presents the results how SERP navigation behavior interacted with reading skills. Navigation had a positive effect indicating that students had better chances to solve the evaluation task correctly when they visited the second SERP. The models including reading skills separately showed main effects for all readings skills on evaluating online information when students did not navigate between two SERPs. When students navigate between the SERPs, the effects of reading on word and sentence level remained unchanged, but the effect of reading comprehension was increased. The combined model showed that only effects of navigation, reading comprehension and their interaction remained significant after taking all reading skills into account.

In the eight items containing one SERP with websites, half the students showed no navigation behavior (about 46% to 67% per item). The results for models examining the impact of navigation on reading effects are presented in Table 4. Again, navigation was highly predictive in all models. The probability to solve an evaluation task rose when students navigated within the items. The models including just one reading skill showed only a main effect of word recognition when students did not visit any of the websites, but no interaction with students‘ navigation behavior was found. In contrast, semantic integration and reading comprehension changed to be predictive for the evaluation of online information when students visited websites. The combined model showed only a significant effect of word reading for students who did not leave the SERP as well as an effect of reading comprehension for students who visited websites connected to the hyperlinks on a SERP.

Discussion

The present study investigated the impact of reading skills on word, sentence, and text level when students evaluate information from search engine result pages (SERPs). In line with hypothesis H1, we found that skills in word recognition, semantic integration, and reading comprehension predicted students’ selection behavior of SERP hyperlinks, although only semantic integration and reading comprehension made a unique contribution. These analyses were deepened by taking characteristics of hyperlinks and students’ navigation behavior into account. Supporting H2 partly, the effect of reading comprehension on hyperlink selection was more pronounced, the more the links differed in their relevance to a search task. Effects of word and sentence level reading were not

Table 1

Effects of reading skills on evaluating online information

	WR				SI				RC				Combined model			
Fixed effects	**Est.**	***SE***	***p***		**Est.**	***SE***	***p***		**Est.**	***SE***	***p***		**Est.**	***SE***	***p***	
word recognition (WR)	.19	.05	<.001	***									.07	.04	.086	
semantic integration (SI)					.21	.05	<.001	***					.10	.05	.028	*
reading comprehension (RC)									.47	.05	<.001	***	.42	.05	<.001	***
ΔR^2	1.8%				0.9%				19.6%				19.3%			

Notes. * $p < .05$; ** $p < .01$; *** $p < .001$.

Table 2

Effects of reading skills on evaluating online information in interaction with the variability in relevance (VIR) within items

	WR				**SI**				**RC**				**Combined model**			
Fixed effects	**Est.**	***SE***	***p***		**Est.**	***SE***	***p***		**Est.**	***SE***	***p***		**Est.**	***SE***	***p***	
word recognition (WR)	.18	.05	<.001	***									.07	.05	.086	
WR : VIR	.03	.03	.141										.00	.03	.499	
semantic integration (SI)					.21	.05	<.001	***					.10	.05	.027	*
SI : VIR					.04	.03	.093						.01	.03	.392	
reading comprehension (RC)									.47	.05	<.001	***	.42	.05	<.001	***
RC : VIR									.10	.03	.001	**	.10	.04	.002	*

Notes. * $p < .05$; ** $p < .01$; *** $p < .001$.

Table 3

Effects of reading skills on evaluating online information depending on students' navigation behavior in items with two SERPs

	WR				**SI**				**RC**				**Combined model**			
Fixed effects	**Est.**	***SE***	***p***		**Est.**	***SE***	***p***		**Est.**	***SE***	***p***		**Est.**	***SE***	***p***	
navigated between SERPs	1.29	.16	<.001	***	1.29	0.16	<.001	***	1.13	0.16	<.001	***	1.08	.16	<.001	***
word recognition (WR)	.25	.12	.015	*									.16	.12	.088	
navigated between SERPs : WR	.09	.16	.276										-.05	.17	.384	
semantic integration (SI)					.25	.12	.015	*					.12	.12	.150	
navigated between SERPs : SI					.25	.17	.065						.18	.17	.149	
reading comprehension (RC)									.52	.13	<.001	***	.45	.14	.001	**
navigated between SERPs : RC									.34	.17	.021	*	.31	.18	.039	*

Notes. Reference category for the navigation variable is "no navigation". * $p < .05$; ** $p < .01$; *** $p < .001$.

Table 4

Effects of reading skills on evaluating online information depending on students' navigation behavior in items containing one SERP with websites

	WR				SI				RC				Combined model			
Fixed effects	**Est.**	***SE***	***p***		**Est.**	***SE***	***p***		**Est.**	***SE***	***p***		**Est.**	***SE***	***P***	
navigated to websites	1.05	.09	<.001	***	.99	.10	<.001	***	.87	.10	<.001	***	.85	.10	<.001	***
word recognition (WR)	.14	.07	.020	*									.14	.07	.026	*
navigated to websites : WR	-.03	.09	.371										-.12	.10	.120	
semantic integration (SI)					.01	.06	.412						-.03	.06	.344	
navigated to websites : SI					.20	.10	.022	*					.14	.10	.086	
reading comprehension (RC)									.07	.06	.120		.02	.07	.381	
navigated to websites : RC									.36	.10	<.001	***	.38	.11	<.001	***

Notes. Reference category for the navigation variable is "no navigation". * $p < .05$; ** $p < .01$; *** $p < .001$.

affected by this task characteristic. Confirming H3, navigation to other SERPs and SERP websites was positively related to students' evaluating skill. Partially supporting H4, reading comprehension was the only skill to interact with students' navigation between SERPs. An interaction of navigation with semantic integration and reading comprehension was also found in tasks providing a SERP with websites. These reading skills explained evaluations of online information only when navigation was actually performed. Interestingly, when students did not visit SERP websites, their word recognition skills were predictive for their evaluation skill.

4.1 Reading processes in web search

The study's results show that several reading processes are involved when students evaluate online information to select hyperlinks from SERPs. Moreover, they give evidence that different reading skills support different strategies that can be applied to process web information (cf. Coiro & Dobler, 2007; Evans, 2008; Wirth et al., 2007). The overall effects of both semantic integration and reading comprehension suggest differences in the width and depth of information processing. Students who are able to capture semantic contexts of fragmented texts like in SERP hyperlinks will select appropriate information. However, some students might just process hyperlink information superficially until they have found one matching the search task to a large degree semantically, whereas others compare and relate every hyperlink from a limited collection in order to identify the most suitable alternative.

As previous studies revealed, the adequate use of structural and semantic cues like the layout of a website or discrepancies in contents will determine the quality of hyperlink evaluations (e.g., Metzger et al., 2010; Rouet et al., 2011). Especially prior content knowledge may play the biggest part for judging and comparing such cues (Lucassen et al., 2013), but the interaction of reading comprehension skills with the task-specific relevance of SERP hyperlinks points at an advantage of skilled readers. It might be easier to identify relevant semantic cues and to make actually use of them for skilled readers than less experienced ones (Rouet et al., 2011). In this respect, reading comprehension could be an important prerequisite for identification and also a supporting skill for setting semantic cues into an appropriate context. Skilled readers might also use semantic cues to identify if information is irrelevant. In that case, they could turn away from irrelevant hyperlinks easier than struggling readers saving limited cognitive resources (cf. Walczyk, 2000).

Support for these interpretations is also given by the results involving students' navigation behavior. Navigation to other SERPs or SERP websites generally supported students' evaluations. Through navigation, students could confirm or falsify their expectations about a link and exclude that SERP information misled them to hasty conclusions (cf. Coiro & Dobler, 2007). When visiting a second SERP, effects of word and sentence level reading skills did not increase, but readers with good comprehension skills were in advantage in selecting useful hyperlinks. Although the direction of this positive effect remains unclear, it seems plausible that reading comprehension and navigation behavior are mutually dependent. On the one hand side, students might navigate because they could not find information that fits a search task semantically (cf. Blackmon, 2012) or is sufficiently relevant and credible (cf. Rieh, 2002). That would mean that navigation to another SERP would be only performed when students elaborated on and compared the hyperlinks of a particular SERP explaining why the effects of word recognition and semantic integration remained unchanged. On the other side, good readers might be able to process the amount of information that was added through navigation more efficiently than less skilled readers. Since constituent skills of reading are more fluent in skilled readers and can be processed largely automatically, they might enable readers to process text information more efficiently requiring less mental effort for the integration of information from multiple sources and decision making (cf. Hamilton et al., 2013; Rouet, 2006; Walczyk, 2000).

Fluency in reading and processing information also explains the increased effect of semantic integration and reading comprehension when students visited websites connected to SERPs. Presumably, experienced readers are in a better position to assess the need for additional information from SERP websites than less skilled readers. The missing effects of semantic integration and reading comprehension for students who did not visit connected websites may look odd at first, but together with the finding of a word recognition effect in the same condition they underline again that students apply different strategies to evaluate online information and that specific reading skills can be supportive depending on the strategy chosen. Although the results cannot uncover specific strategies of information processing, they complement studies that found students to use both heuristic and systematic processing strategies in order to select hyperlinks (e.g., Salmerón et al., 2015). The results point at the importance to regard what students actually did while task processing in terms of navigation (Salmerón et al., 2005). Evaluation strategies and their conditions, though, need to be investigated with more fine-grained data, for example, as from think-aloud studies that can provide valuable insights into reasons for specific navigation behaviors and strategies of information processing (e.g., Gerjets et al., 2011).

4.2 Limitations

There are at least three limitations that should be considered in this study. First, the Test for the Evaluation of Online Information (TEO), which was used to measure students' skills in evaluating online information, simulates a search engine environment but it also restricted to predefined functions of that closed environment. That is, test authors have decided on the quality and volume of information that can be accessed and have to be taken into account for evaluations. Therefore, the TEO cannot represent the variety of actions web users usually apply (e.g., free choice of search terms), the amount of available online information (e.g., unspecified information quantities), or the strategic use of web search features (e.g., making use of knowledge about search engine algorithms). As a consequence, TEO results cannot be generalized to give a comprehensive picture of behaviors when seeking information in an open web space. However, it is the major advantage of the TEO that the process of information seeking is standardized. Reproducible search results are normally not given in open search. Since both web users' actions and available information space are limited, the items spotlight micro-processes in web search and allow for in-depth analyses. To make selection criteria of students transparent (e.g., relevance, trustworthiness, credibility, prior knowledge), a further development of the TEO would be useful. Students could be asked for the reason why they have selected a particular hyperlink after task completion. Alternatively, they could also rate the provided hyperlink according to several quality aspects, comparable to the conducted relevance ratings in this study. Such an extension, however, should be considered carefully since students might align their response behavior according to given criteria.

Second, one could argue that many students did not follow the instructions because they did not navigate in tasks allowing for visiting other pages than the initial SERP. Indeed, students were not directly instructed to look at all available information but they were told that it is available. Additionally, a reminder was permanently visible (grey panel on the left side of Figure 1). Presumably, students did not ignore the instruction but acted naturally by not visiting all available information according to their experiences with web search and search engines. In that case, the TEO items would have worked well in providing face-valid conditions of web search.

Finally, reading skills are not the only important constituents for evaluating online information. In addition to prior knowledge about contents and structural features which has been found to affect the evaluation of surface and semantic cues fundamentally (e.g., Lucassen et al., 2013; Rouet et al., 2011), web users' memory skills, individual perceived cognitive load, or learnt strategies to overcome memory deficits (e.g., bookmarking, using tabs) can have a strong impact on the allocation of cognitive resources affecting how students compare and weight web information (cf. DeStefano & LeFevre, 2007). Correlation based analyses like we did can give first insights into relationships between individual cognitive skills, features of texts provided in web search and indicators of actual behavior of web users. Nevertheless, other empirical approaches like, for example, think-aloud studies or experimental designs stressing cognitive resources during web search tasks are needed to cross-validate and strengthen our interpretations of the present study's results.

4.3 Conclusions

The study shows that partial processes of reading (i.e., word recognition, semantic integration and reading comprehension) are essential when seeking information with the aid search engines. We interpreted the results in that reading skills on word, sentence, and text level support different information processing strategies that students can choose when evaluating online information from SERPs. Especially proficient text level skills seem to support readers in the identification and the use of semantic cues in SERP hyperlinks reflecting their relevance to a search task. Furthermore, students' individual reading skills interact with their behavior in visiting other SERPs or websites that are connected to SERP hyperlinks. This indicates that skilled readers in comparison to poor readers are able to allocate their cognitive resources more effectively when dealing with online information making navigation as an event of receiving more information less effortful. Uncovering in-depth mechanisms in this interplay of reading skills, navigation behavior and evaluation of online information will be a challenge for future research. In educational means, the results show in general that students' skill to sensibly select online information while doing a web search rests on component skills that can be learned and trained. Poor readers, though, will not get a fresh start in the information age (cf. Walraven et al., 2008). The deficits in their reading skills can impair their use of the 'new' media if not alleviated by adequate education and intervention.

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References

Balota, D. A., Cortese, M. J., Sergent-Marshall, S. D., Spieler, D. H., & Yap, M. J. (2004). Visual Word Recognition of Single-Syllable Words. *Journal of Experimental Psychology: General*, *133*(2), 283–316.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Blackmon, M. H. (2012). Information scent determines attention allocation and link selection among multiple information patches on a webpage. *Behaviour & Information Technology*, *31*(1), 3–15. https://doi.org/10.1080/0144929X.2011.599041

Brand-Gruwel, S., & Stadtler, M. (2011). Solving information-based problems: Evaluating sources and information. *Learning and Instruction*, *21*(2), 175–179. https://doi.org/10.1016/j.learninstruc.2010.02.008

Brand-Gruwel, S., Wopereis, I., & Walraven, A. (2009). A descriptive model of information problem solving while using internet. *Computers & Education*, *53*(4), 1207–1217. https://doi.org/10.1016/j.compedu.2009.06.004

Coiro, J., & Dobler, E. (2007). Exploring the online reading comprehension strategies used by sixth-grade skilled readers to search for and locate information on the Internet. *Reading Research Quarterly*, *42*(2), 214–257. https://doi.org/10.1598/RRQ.42.2.2

De Boeck, P., Bakker, M., Zwitser, R., Nivard, M., Hofman, A., Tuerlinckx, F., & Partchev, I. (2011). The estimation of item response models with the lmer function from the lme4 package in R. *Journal of Statistical Software*, *39*(12), 1–28.

DeStefano, D., & LeFevre, J.-A. (2007). Cognitive load in hypertext reading: A review. *Computers in Human Behavior*, *23*(3), 1616–1641. https://doi.org/10.1016/j.chb.2005.08.012

Evans, J. S. B. T. (2008). Dual-Processing Accounts of Reasoning, Judgment, and Social Cognition. *Annual Review of Psychology*, *59*(1), 255–278. https://doi.org/10.1146/annurev.psych.59.103006.093629

Feierabend, S., Karg, U., & Rathgeb, T. (2013). *JIM-Studie 2013. Jugend, Information, (Multi-) Media [JIM-Study. Youth, Information, (Multi-) Media]*. Stuttgart: MPFS.

Flanagin, A. J., & Metzger, M. J. (2007). The role of site features, user attributes, and information verification behaviors on the perceived credibility of web-based information. *New Media & Society*, *9*(2), 319–342. https://doi.org/10.1177/1461444807075015

Gerjets, P., Kammerer, Y., & Werner, B. (2011). Measuring spontaneous and instructed evaluation processes during Web search: Integrating concurrent thinking-aloud protocols and eye-tracking data. *Learning and Instruction*, *21*(2), 220–231. https://doi.org/10.1016/j.learninstruc.2010.02.005

Gigerenzer, G., & Gaissmaier, W. (2011). Heuristic Decision Making. *Annual Review of Psychology*, *62*(1), 451–482. https://doi.org/10.1146/annurev-psych-120709-145346

Hahnel, C., Goldhammer, F., Naumann, J., & Kröhne, U. (2016). Effects of linear reading, basic computer skills, evaluating online information, and navigation on reading digital text. *Computers in Human Behavior*, *55*, 486–500. https://doi.org/10.1016/j.chb.2015.09.042

Hamilton, S. T., Freed, E. M., & Long, D. L. (2013). Modeling Reader and Text Interactions During Narrative Comprehension: A Test of the Lexical Quality Hypothesis. *Discourse Processes*, *50*(2), 139–163. https://doi.org/10.1080/0163853X.2012.742001

Hilligoss, B., & Rieh, S. Y. (2008). Developing a unifying framework of credibility assessment: Construct, heuristics, and interaction in context. *Information Processing & Management*, *44*(4), 1467–1484. https://doi.org/10.1016/j.ipm.2007.10.001

Juvina, I., & van Oostendorp, H. (2008). Modeling Semantic and Structural Knowledge in Web Navigation. *Discourse Processes*, *45*(4–5), 346–364. https://doi.org/10.1080/01638530802145205

Kammerer, Y., & Gerjets, P. (2014). The Role of Search Result Position and Source Trustworthiness in the Selection of Web Search Results When Using a List or a Grid Interface. *International Journal of Human-Computer Interaction*, *30*(3), 177–191. https://doi.org/10.1080/10447318.2013.846790

Kiefer, T., Robitzsch, A., & Wu, M. (2015). *TAM: Test Analysis Modules*. Retrieved from http://CRAN.R-project.org/package=TAM

Kintsch, W. (1998). *Comprehension: A Paradigm for Cognition*. Cambridge University Press.

Kröhne, U., Hahnel, C., Schiepe-Tiska, A., & Goldhammer, F. (2013, August). *Analyzing Mode Effects of PISA Print Reading Including a Comparison of Time-related Information.* Presented at the 15th Biennal Conference of the European Association for Research on Learning and Instruction (EARLI), Munich, Germany.

Lawless, K. A., & Schrader, P. G. (2008). Where do we go now? Understanding research on navigation in complex digital environments. In D. J. Leu & J. Coiro (Eds.), *Handbook of New Literacies* (pp. 267–296). Hillsdale, NJ: Lawrence Erlbaum Associates.

Liu, X., Chin, J., Payne, B. R., Fu, W.-T., Morrow, D. G., & Stine-Morrow, E. A. L. (2016). Adult age differences in information foraging in an interactive reading environment. *Psychology and Aging*, *31*(3), 211–223. https://doi.org/10.1037/pag0000079

Lucassen, T., Muilwijk, R., Noordzij, M. L., & Schraagen, J. M. (2013). Topic familiarity and information skills in online credibility evaluation. *Journal of the American Society for Information Science and Technology*, *64*(2), 254–264. https://doi.org/10.1002/asi.22743

Masters, G. N. (2010). The Partial Credit Model. In M. L. Nering & R. Ostini (Eds.), *Handbook of polytomous item response theory models* (pp. 109–122). New York, NY: Routledge.

Metzger, M. J. (2007). Making sense of credibility on the Web: Models for evaluating online information and recommendations for future research. *Journal of the American Society for Information Science and Technology*, *58*(13), 2078–2091. https://doi.org/10.1002/asi.20672

Metzger, M. J., Flanagin, A. J., & Medders, R. B. (2010). Social and Heuristic Approaches to Credibility Evaluation Online. *Journal of Communication*, *60*(3), 413–439. https://doi.org/10.1111/j.1460-2466.2010.01488.x

Naumann, J., Richter, T., Christmann, U., & Groeben, N. (2008). Working memory capacity and reading skill moderate the effectiveness of strategy training in learning from hypertext. *Learning and Individual Differences*, *18*(2), 197–213. https://doi.org/10.1016/j.lindif.2007.08.007

Organisation for Economic Co-operation and Development (OECD). (2011). *PISA 2009 Results: Students On Line*. OECD Publishing. Retrieved from http://www.oecd-ilibrary.org/education/pisa-2009-results-students-on-line_9789264112995-en

Organisation for Economic Co-operation and Development (OECD). (2013). *PISA 2012 Assessment and Analytical Framework*. OECD Publishing. Retrieved from http://dx.doi.org/10.1787/9789264190511-en

Organisation for Economic Co-operation and Development (OECD). (2014). *PISA 2012 Technical Report*. OECD Publishing. Retrieved from http://www.oecd.org/pisa/pisaproducts/PISA-2012-technical-report-final.pdf

Pan, B., Hembrooke, H., Joachims, T., Lorigo, L., Gay, G., & Granka, L. (2007). In Google We Trust: Users' Decisions on Rank, Position, and Relevance. *Journal of Computer-Mediated Communication*, *12*(3), 801–823. https://doi.org/10.1111/j.1083-6101.2007.00351.x

Perfetti, C. (2007). Reading Ability: Lexical Quality to Comprehension. *Scientific Studies of Reading*, *11*(4), 357–383.

Perfetti, C., & Stafura, J. (2014). Word Knowledge in a Theory of Reading Comprehension. *Scientific Studies of Reading*, *18*(1), 22–37. https://doi.org/10.1080/10888438.2013.827687

Pfaff, Y., & Goldhammer, F. (2012). *Measuring individual differences in ICT literacy: Accessing and Evaluating Information*. Paper presented at the 14th EARLI Conference, Exeter, UK.

R Core Team. (2015). *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from http://www.R-project.org/

Ratcliff, R., Gomez, P., & McKoon, G. (2004). A diffusion model account of the lexical decision task. *Psychological Review*, *111*, 159–182. https://doi.org/10.1037/0033-295X.111.1.159

Richter, T., Isberner, M.-B., Naumann, J., & Kutzner, Y. (2012). Prozessbezogene Diagnostik von Lesefähigkeiten bei Grundschulkindern. *Zeitschrift Für Pädagogische Psychologie*, *26*(4), 313–331. https://doi.org/10.1024/1010-0652/a000079

Rieh, S. Y. (2002). Judgment of information quality and cognitive authority in the Web. *Journal of the American Society for Information Science and Technology*, *53*(2), 145–161. https://doi.org/10.1002/asi.10017

Rieh, S. Y., Kim, Y.-M., & Markey, K. (2012). Amount of invested mental effort (AIME) in online searching. *Information Processing & Management*, *48*(6), 1136–1150. https://doi.org/10.1016/j.ipm.2012.05.001

Rouet, J.-F. (2006). *The skills of document use: from text comprehension to Web-based learning*. Mahwah, NJ: Erlbaum.

Rouet, J.-F., Ros, C., Goumi, A., Macedo-Rouet, M., & Dinet, J. (2011). The influence of surface and deep cues on primary and secondary school students' assessment of relevance in Web menus. *Learning and Instruction*, *21*(2), 205–219. https://doi.org/10.1016/j.learninstruc.2010.02.007

Sabatini, J. (2015). *Understanding the Basic Reading Skills of U.S. Adults: Reading Components in the PIAAC Literacy Survey*. Princeton, N.J.: Educational Testing Service.

Salmerón, L., Cañas, J. J., Kintsch, W., & Fajardo, I. (2005). Reading Strategies and Hypertext Comprehension. *Discourse Processes*, *40*(3), 171–191. https://doi.org/10.1207/s15326950dp4003_1

Salmerón, L., Kammerer, Y., & García-Carrión, P. (2013). Searching the Web for conflicting topics: Page and user factors. *Computers in Human Behavior*, *29*(6), 2161–2171. https://doi.org/10.1016/j.chb.2013.04.034

Salmerón, L., Naumann, J., García, V., & Fajardo, I. (2016). Scanning and deep processing of information in hypertext: an eye tracking and cued retrospective think-aloud study. *Journal of Computer Assisted Learning*. https://doi.org/10.1111/jcal.12152

Samuels, S. J., & Flor, R. F. (1997). The importance of automaticity for developing expertise in reading. *Reading & Writing Quarterly*, *13*, 107–121.

Schroeder, S. (2011). What Readers Have and Do: Effects of Students' Verbal Ability and Reading *Journal of Educational Psychology*, *103*(4), 877–896. https://doi.org/10.1037/a0023731

van Deursen, A. J. A. M., & van Dijk, J. A. G. M. (2009). Using the Internet: Skill related problems in users' online behavior. *Interacting with Computers*, *21*(5–6), 393–402. https://doi.org/10.1016/j.intcom.2009.06.005

Voss, A., Rothermund, K., & Voss, J. (2004). Interpreting the parameters of the diffusion model: An empirical validation. *Memory & Cognition*, *32*(7), 1206–1220.

Voss, A., & Voss, J. (2007). Fast-dm: A free program for efficient diffusion model analysis. *Behavior Research Methods*, *39*(4), 767–775.

Walczyk, J. J. (2000). The interplay between automatic and control processes in reading. *Reading Research Quarterly*, *35*(4), 554–566.

Walraven, A., Brand-Gruwel, S., & Boshuizen, H. P. A. (2008). Information-problem solving: A review of problems students encounter and instructional solutions. *Computers in Human Behavior*, *24*(3), 623–648. https://doi.org/10.1016/j.chb.2007.01.030

Wirth, W., Böcking, T., Karnowski, V., & von Pape, T. (2007). Heuristic and Systematic Use of Search Engines. *Journal of Computer-Mediated Communication*, *12*(3), 778–800. https://doi.org/10.1111/j.1083-6101.2007.00350.x

Appendix

Overview of content, characteristics, and easiness of the TEO items

Item	Search task	Number of hyperlinks	Variability in relevance	Type	Item Easiness (*SE*)
item 1	How to stop smoking	6	0.76	SERP only	-0.57 (0.13)
item 2	Prepare a presentation on autoimmune diseases	6	0.08	SERP only	0.24 (0.13)
item 3	How to replace a light bulb	6	1.86	SERP only	-1.78 (0.16)
item 4	Prepare a presentation on migraine	6	0.17	SERP only	-0.45(0.14)
item 5	How to clean a drain	10	-0.37	two SERPs	-1.44 (0.15)
item 6	Learning about climbing sports	10	-0.39	two SERPs	0.14 (0.13)
item 7	Learning about sailing sports	10	-0.34	two SERPs	-1.03 (0.14)
item 8	Prepare a presentation on alternative energy sources	10	-0.45	two SERPs	-1.14 (0.14)
item 9	Learning about diving sports	5	0.57	SERP with websites	-1.31 (0.14)
item 10	Learning about lunar eclipse	3	-1.91	SERP with websites	0.30 (0.13)
item 11	How to treat a common cold	5	-1.17	SERP with websites	-2.42 (0.18)
item 12	How to change a bicycle chain	3	-0.85	SERP with websites	-0.66 (0.14)
item 13	Prepare a presentation on computer viruses	5	1.05	SERP with websites	0.54 (0.14)
item 14	How to treat a sunstroke	3	1.20	SERP with websites	-0.10 (0.13)
item 15	Learning about algae	5	0.81	SERP with websites	-2.59 (0.19)
item 16	How to treat acne	3	-1.02	SERP with websites	-0.91 (0.14)

Note. Values of ‘variability of variance’ are *z*-standardized. Item easiness was estimated from the baseline model.

APPENDIX

1. Erklärung zur Promotionsordnung
2. Eidesstattliche Versicherung
3. Erklärung zu bisherigen Promotionsverfahren
4. Stellungnahme zu den Kriterien einer publikationsbasierten Dissertation
5. Erklärung über die Eigenleistung
6. Bestätigung der Einreichung
7. Lebenslauf

Erklärung zur Promotionsordnung

Ich erkläre hiermit, dass mir die Promotionsordnung der Mathematisch-Naturwissenschaftlichen Fachbereiche der Goethe Universität Frankfurt am Main bekannt ist.

Frankfurt am Main, den 18. April 2017

Carolin Hahnel

Eidesstattliche Versicherung

Ich erkläre hiermit, dass ich die vorgelegte Dissertation mit dem Titel *Demands and Cognitive Processes in Reading Digital Text* selbständig angefertigt und mich nicht anderer Hilfsmittel als der in ihr angegebenen bedient habe. Insbesondere versichere ich, dass alle Entlehnungen aus anderen Schriften mit Angabe der betreffenden Schrift gekennzeichnet sind. Ich habe die Grundsätze der guten wissenschaftlichen Praxis beachtet und habe nicht die Hilfe einer kommerziellen Promotionsvermittlung in Anspruch genommen.

Frankfurt am Main, den 18. April 2017

Carolin Hahnel

Erklärung zu bisherigen Promotionsverfahren

Ich erkläre hiermit, dass ich mich bisher keiner Doktorprüfung im Mathematisch-Naturwissenschaftlichen Bereich unterzogen habe.

Frankfurt am Main, den 18. April 2017

Carolin Hahnel

Stellungnahme zu den Kriterien einer publikationsbasierten Dissertation

Kriterien für kumulative Dissertationen im Fachbereich Psychologie und Sportwissenschaften, Goethe Universität Frankfurt (nach Beschluss im Fachbereichsrat gültig ab 11.06.2015)

(1) Die kumulative Dissertation soll in der Regel 3 Schriften umfassen, die aus den letzten 5 Jahren stammen sollen.

Erklärung: Die Dissertation umfasst eine Schrift aus dem Jahr 2016 sowie zwei derzeit in Fachzeitschriften eingereichte Manuskripte.

(2) Die Schriften sollen im Wesentlichen einem zusammenhängenden Forschungsprogramm entstammen. Die jeweils verfolgten Forschungsfragen sollen sich sinnvoll zueinander in Beziehung setzen lassen.

Erklärung: Die Schriften thematisieren das Lesen und Verstehen digital präsentierter Texte und basieren alle auf Forschungsdaten, die im Rahmen der Nationalen PISA Begleitforschung 2012 zum Computerbasierten Assessment (CBA) erfasst wurden.

(3) Der Kandidat oder die Kandidatin soll bei 2 Publikationen Erstautor/Erstautorin sein, bei einer weiteren Publikation kann er/sie Koautor/Koautorin sein. Eine geteilte Erstautorenschaft wird für jeden der Erstautoren anteilig gewichtet (bei 2 Erstautoren eine 1/2 Erstautorenschaft, bei 3 eine 1/3 Erstautorenschaft usw.).

Erklärung: Ich bin in allen drei Schriften Erstautorin. Es gibt keine geteilten Erstautorenschaften.

(4) Die drei Schriften sollen zur Veröffentlichung zumindest eingereicht sein. Der aktuelle Status ist detailliert darzulegen (Publikationsorgan und Status wie eingereicht, in revision, conditional accept usw.).

(5) Mindestens 2 der 3 Schriften müssen in guten oder sehr guten, in der Regel englischsprachigen, Zeitschriften mit Peer-Review eingereicht sein.

(6) Eine der 3 Schriften kann als Publikation in einem einschlägigen Lehrbuch, Enzyklopädieband oder einem anderen für das jeweilige Fach bedeutsamen Publikationsorgan, jeweils mit Peer-Review, eingereicht oder veröffentlicht sein.

Erklärung zu (4)-(6): Eine bereits publizierte Schrift ist bei *Computers in Human Behavior* (Impact Factor 2015: 2.880) erschienen. Eine weitere Schrift wurde am 16.04.2017 an diese Fachzeitschrift eingereicht. Die dritte Schrift wurde nach Revision bei *Learning and Individual Differences* (Impact Factor 2015: 1.631) am

16.04.2017 wiedereingereicht. Alle Schriften sind englischsprachig. Die genannten Fachzeitschriften arbeiten mit einem Peer-Review-Verfahren.

(7) Die als Dissertation vorgelegte Abhandlung soll über die zusammengestellten Publikationen hinaus einen zusätzlichen Text enthalten, in welchem eine kritische Einordnung der eigenen Publikationen aus einer übergeordneten Perspektive heraus vorgenommen wird. Dieser Text sollte einen Umfang von ca. 30 Seiten haben. Es sollen die Fragestellungen theoretisch entwickelt werden, die empirischen Arbeiten und ihre Ergebnisse so dargestellt werden, dass sie auch ohne Lesen der Einzelarbeiten nachvollziehbar sind und es soll eine Gesamtdiskussion enthalten, die die Fragestellungen beantwortet und den Erkenntnisgewinn der Arbeit herausstellt.

(8) Die Dissertation muss eine Erklärung enthalten, in der die Eigenleistung des Kandidaten/der Kandidatin dargestellt wird. Insbesondere bei Schriften mit Koautoren, aber auch bei in Einzelautorenschaft entstandenen Schriften, die oft auch im Rahmen von Abteilungsprojekten, Drittmittelprojekten, Projektverbünden usw. entstanden sind, soll dargelegt werden, welchen Anteil die Kandidaten an Entwicklung der Fragestellung, Design, Durchführung, Auswertung der empirischen Studie(n) und an dem Abfassen der einzelnen Beiträge hatten. Diese Erklärung ist von Betreuer und/oder Koautoren zu bestätigen.

Erklärung: Die entsprechenden Texte sind enthalten.

(9) In besonders begründeten Fällen kann von diesen Richtlinien abgewichen werden.

(10) Bei den vorgeschlagenen Kriterien handelt es sich um Empfehlungen. Es wird explizit darauf hingewiesen, dass natürlich nach wie vor die jeweilige Promotionsordnung, die Beschlüsse des Promotionsausschusses und die von den Gutachtern erstellten Gutachten entscheidend für das Verfahren sind.

Anmerkung: Satz (8) gilt auch für Dissertationen, die als Monographie vorgelegt werden.

Frankfurt am Main, den 18. April 2017

Carolin Hahnel

Erklärung über die Eigenleistung

Die vorliegende Dissertation *Demands and Cognitive Processes in Reading Digital Text* beinhaltet drei Manuskripte, die zum Zeitpunkt der Eröffnung des Promotionsverfahrens in internationalen Fachzeitschriften veröffentlicht oder zur Veröffentlichung eingereicht worden sind. Alle in der Dissertation beschriebenen Studien basieren auf den Daten der Nationalen Begleitstudie zum computerbasierten Assessment (CBA) im *Programme for International Student Assessment* (PISA) 2012. Diese Begleitstudie wurde im Rahmen des *Zentrums für Internationale Bildungsvergleichsstudien* (ZIB) gefördert. Das Design der nationalen Begleitstudie, übergeordnete Projektziele, Stichprobenziehung sowie eine Vorauswahl der eingesetzten Testverfahren wurden durch die Projektleiter Prof. Dr. Goldhammer, Dr. Ulf Kröhne und Prof. Dr. Johannes Naumann entwickelt und bestimmt. Die Verfasserin der Dissertation, Carolin Hahnel, arbeitete als wissenschaftliche Mitarbeiterin im Projekt. Sie war an der computerbasierten Implementation neuer sowie Überarbeitung bereits bestehender Testverfahren, Konzeption und Durchführung einer Vorstudie (Pilotierung im Zeitraum März 2012, gemeinsam mit der *Technischen Universität München* [TUM] *School of Education*), Datenerhebung und Durchführung der Hauptstudie (Zeitraum April bis Juni 2012, gemeinsam mit dem *Data Processing and Research Center* [IEA DPC]) sowie an der Datenaufbereitung und Dokumentation maßgeblich beteiligt bzw. dafür verantwortlich. Studie 1 und 2 basieren zudem auf Daten des computerbasierten Assessments von PISA 2012 (Digital Reading Assessment, im Auftrag der *Organisation for Economic Co-operation and Development* [OECD]). Die Ergebnis- und Logdaten dieses Assessments standen dem Projektteam seit 2014 zur Verfügung.

Studie 1. Hahnel, C., Goldhammer, F., Kröhne, U., & Naumann, J. (in Begutachtung, *Learning and Individual Differences*). Reading digital text involves working memory updating based on task characteristics and reader behavior.

Das Manuskript wurde am 16.04.2017 nach Revision bei der Zeitschrift *Learning and Individual Differences* eingereicht. Die Erstautorin war federführend für die Konzeption des Manuskripts einschließlich der Entwicklung der Fragestellungen und Datenanalysen verantwortlich. Die Argumentationslinie sowie die Ergebnisse wurden mit allen Mitautoren ausführlich besprochen und diskutiert. Die Erstautorin verfasste das

Manuskript selbstständig; die Mitautoren gaben inhaltliche und sprachliche Rückmeldungen.

Studie 2. Hahnel, C., Goldhammer, F., Naumann, J., & Kröhne, U. (2016). Effects of linear reading, basic computer skills, evaluating online information, and navigation on reading digital text. *Computers in Human Behavior*, *55*, 486–500.

Das Manuskript wurde am 15.05.2015 in der Zeitschrift *Computers in Human Behavior* eingereicht und am 26.09.2015 nach Revision zur Veröffentlichung angenommen. Die Fragestellung wurde von der Erstautorin hauptverantwortlich unter Mitwirkung aller Mitautoren entwickelt. Die statistischen Analysen wurden von der Erstautorin eigenständig durchgeführt, wobei das Vorgehen und die Ergebnisse intensiv mit den Mitautoren besprochen und diskutiert wurden. Die Erstautorin war federführend für das Abfassen des Manuskripts verantwortlich, das von den Mitautoren inhaltlich und sprachlich überarbeitet wurde. Nach der ersten Begutachtung des Manuskripts war die Erstautorin federführend für die Überarbeitung des Manuskriptes zuständig. Die Anmerkungen von drei externen Gutachtern wurden von allen Autoren diskutiert und für die Manuskriptüberarbeitung abgestimmt.

Studie 3. Hahnel, C., Goldhammer, F., Kröhne, U., & Naumann, J. (in Begutachtung, *Computers in Human Behavior*). The role of reading for the evaluation of online information gathered from search engine environments.

Das Manuskript wurde am 16.04.2017 in der Fachzeitschrift *Computers in Human Behavior* eingereicht. Die Erstautorin entwickelte die Fragestellung und führte die statistische Auswertung eigenständig durch. Die Konzeption und Ergebnisse wurden mit den Mitautoren ausführlich besprochen und diskutiert. Die Erstautorin war federführend für das Abfassen des Manuskripts verantwortlich und erhielt durch die Mitautoren inhaltliche und sprachliche Anregungen zur Überarbeitung.

Frankfurt am Main, den 18. April 2017

Carolin Hahnel, MSc. Psych.
Verfasserin der Dissertation

Prof. Dr. Frank Goldhammer
Betreuer der Dissertation

Bestätigung der Einreichungen (1/2)

Study 1: Hahnel, C., Goldhammer, F., Kröhne, U., & Naumann, J. (under review, *Learning and Individual Differences*). Reading digital text involves working memory updating based on task characteristics and reader behavior.

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Bestätigung der Einreichungen (2/2)

Study 3: Hahnel, C., Goldhammer, F., Kröhne, U., & Naumann, J. (under review, *Computers in Human Behavior*). The role of reading for the evaluation of online information gathered from search engine environments.

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