Effects of Linear Reading, Basic Computer Skills, Evaluating Online Information, and Navigation on Reading Digital Text

Carolin Hahnel [ab], Frank Goldhammer [ab], Johannes Naumann [ca] & Ulf Kröhne [a]

[a] German Institute for International Educational Research (DIPF), Frankfurt am Main (Germany)

[b] Centre for International Student Assessment (ZIB), Germany

[c] Goethe University, Frankfurt am Main (Germany)

accepted for publication in *Computers in Human Behavior*

DOI: 10.1016/j.chb.2015.09.042

Correspondence concerning this article should be addressed to:

Carolin Hahnel, German Institute for International Educational Research (DIPF)

Schlossstraße 29, 60486 Frankfurt am Main, Germany

Phone: +49 69 24 708 727

Email: hahnel@dipf.de

Abstract

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.

Keywords

Digital reading; Hypertext reading; Navigation behavior; Basic computer skills; Evaluating online information.

Effects of Linear Reading, Basic Computer Skills, Evaluating Online Information, and Navigation on Reading Digital Text

Introduction

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, 2013). 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, ICT 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 et al., 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 a fictional homepage of the 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).

Insert Figure 1 about here

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 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 et al., 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 et al., 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. According to Naumann's analyses, 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 ICT, 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 and colleagues (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 performances in the two clusters were comparable. 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 1and Section 1.1, Digital Reading).

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 ($\alpha = .88$, $\omega_t = .87$).

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.

Insert Figure 2 about here

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).

Insert Figure 3 about here

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 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 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.

Insert Figure 4 about here

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.

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 $p < .001$.

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 $p < .001$.

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%).

Insert Figure 5 about here

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 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. * $p < .05$, ** $p < .01$, *** $p < .001$.

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

Insert Figure 6 about here

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, Kinzer, Coiro &

Cammack, 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 (Salmerón & García, 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. In contrast, 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 et al., 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, Tricot & Mariné, 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 (ICT) 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 ICT 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).

Acknowledgements

This research was funded by the Centre for International Student Assessment. We are grateful to Corinna Dziudzia and three anonymous reviewers for their helpful comments during the expansion of this paper. Furthermore, we thank Keri Hartmann for proofreading.

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. http://doi.org/10.1016/j.chb.2008.12.017

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. http://doi.org/10.1108/17415650580000031

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

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. http://doi.org/10.1177/1086296X11421979

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. http://doi.org/10.1598/RRQ.42.2.2

Davis, D. S., & Neitzel, C. (2012). Collaborative sense-making in print and digital text environments. *Reading and Writing*, *25*(4), 831–856. http://doi.org/10.1007/s11145-011-9302-2

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. http://doi.org/10.1007/BF00892243

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. http://doi.org/10.1016/j.compedu.2012.03.014

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. http://doi.org/10.1027/1015-5759/a000153

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. http://doi.org/10.1080/0144929051233131848

Imai, K., Keele, L., & Tingley, D. (2010). A general approach to causal mediation analysis. *Psychological Methods*, *15*(4), 309–334. http://doi.org/10.1037/a0020761

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. http://doi.org/10.2190/DVAP-DE23-3XMV-9MXH

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. Retrieved from http://www.readingonline.org/newliteracies/lit_index.asp?HREF=/newliteracies/leu

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., Fairchild, A. J., & Fritz, M. S. (2007). Mediation Analysis. *Annual Review of Psychology*, *58*(1), 593–614. http://doi.org/10.1146/annurev.psych.58.110405.085542

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. Retrieved from http://www.pewinternet.org/~/media/Files/Reports/2013/PIP_TeensandTechnology2013.pdf

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. http://doi.org/10.1016/j.chb.2008.06.005

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. http://doi.org/10.1016/j.lindif.2007.08.007

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. 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

Preacher, K. J., & Kelley, K. (2011). Effect size measures for mediation models: Quantitative strategies for communicating indirect effects. *Psychological Methods*, *16*(2), 93–115. http://doi.org/10.1037/a0022658

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. Retrieved from http://www.pisa.tum.de/fileadmin/w00bgi/www/Berichtband_und_Zusammenfassung_2012/PISA_EBook_ISBN3001.pdf

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. http://doi.org/10.1002/asi.10017

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. Retrieved from http://www.niu.edu/britt/recent_papers/pdfs/RouetBritt_chapter_for_McCrudden.pdf

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. http://doi.org/10.1007/s11409-007-9011-z

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. http://doi.org/10.1016/j.learninstruc.2010.02.007

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

Salmerón, L., & García, V. (2011). Reading skills and children's navigation strategies in hypertext. *Computers in Human Behavior*, *27*(3), 1143–1151. http://doi.org/10.1016/j.chb.2010.12.008

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. http://doi.org/10.1016/j.compedu.2008.08.003

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

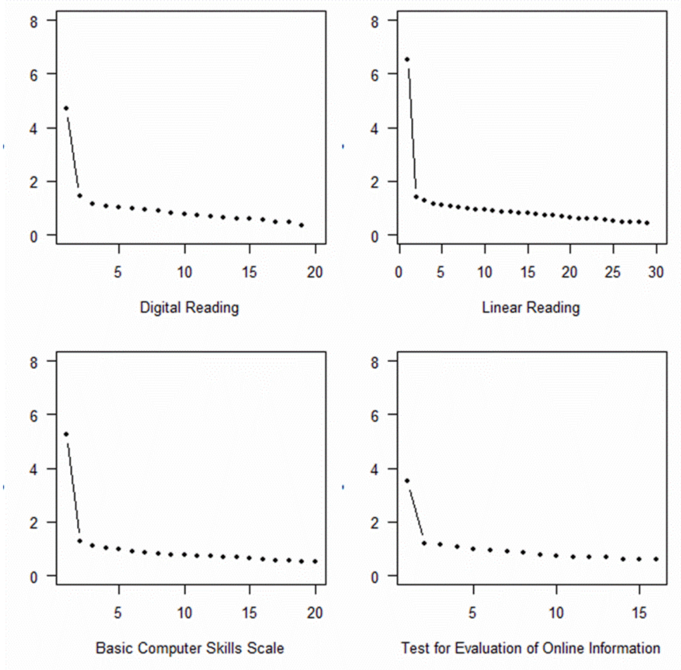


Figure A. Scree plots of the scales for digital reading (upper left), linear reading (upper right), basic computer skills (lower left), and evaluating online information (lower right). Course of the eigenvalues based on the matrix of inter-item correlations (Kendalls' correlation coefficients).

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.

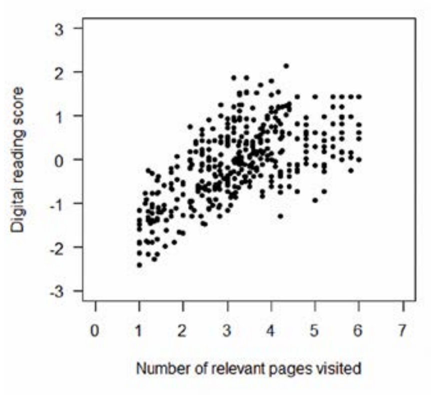


Figure C.1. Scatter plot of students' digital reading performance and the number of relevant pages visited.

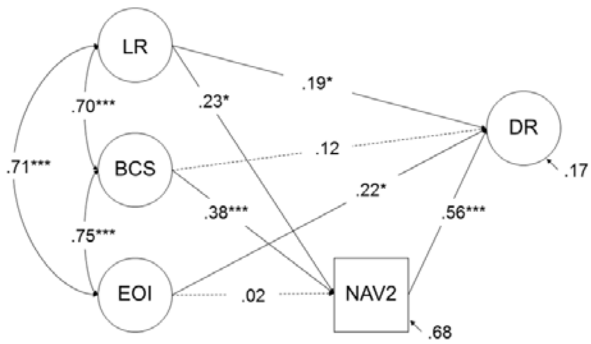


Figure C.2. Estimated mediation model with standardized regression coefficients. LR = Linear reading. BCS = Basic computer skills. EOI = Evaluating online information. NAV2 = Number of relevant pages visited. DR = Digital Reading. Solid arrows describe significant paths; dashed arrows describe non-significant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

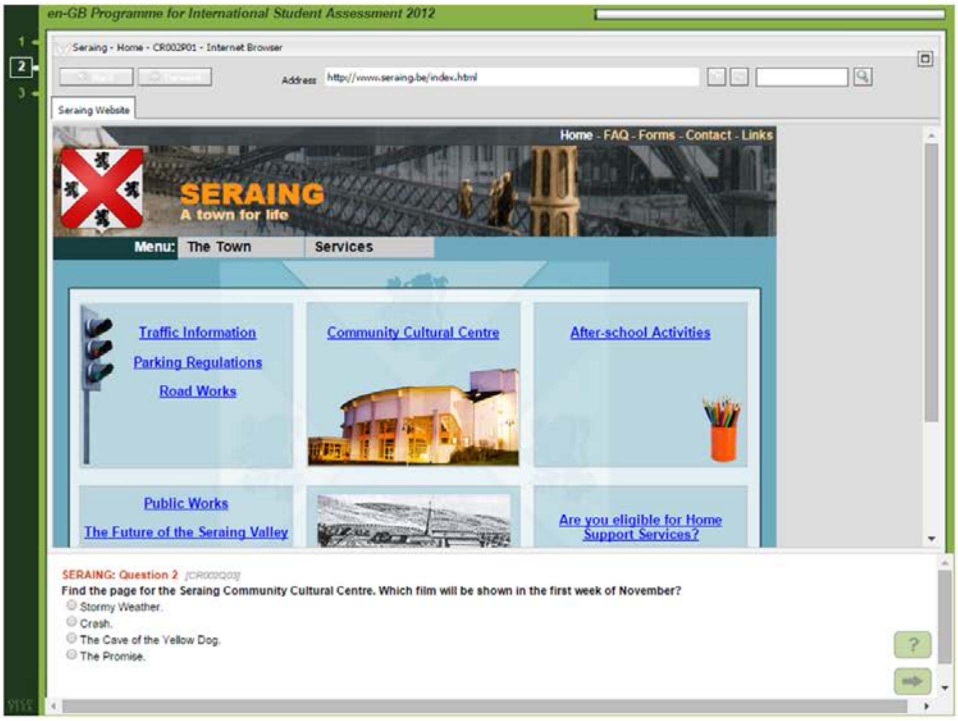
Apel, M. (2012, May 20). Anthocharis cardamines female. Own work. Licensed under CC BY 3.0 via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Anthocharis_cardamines_female_MichaD.jpg#/media/File:Anthocharis_cardamines_female_MichaD.jpg

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

(a) Hypertext “Seraing”: Locating information about a movie



(b) Hypertext “Sports Club”: Recommending a fitness studio

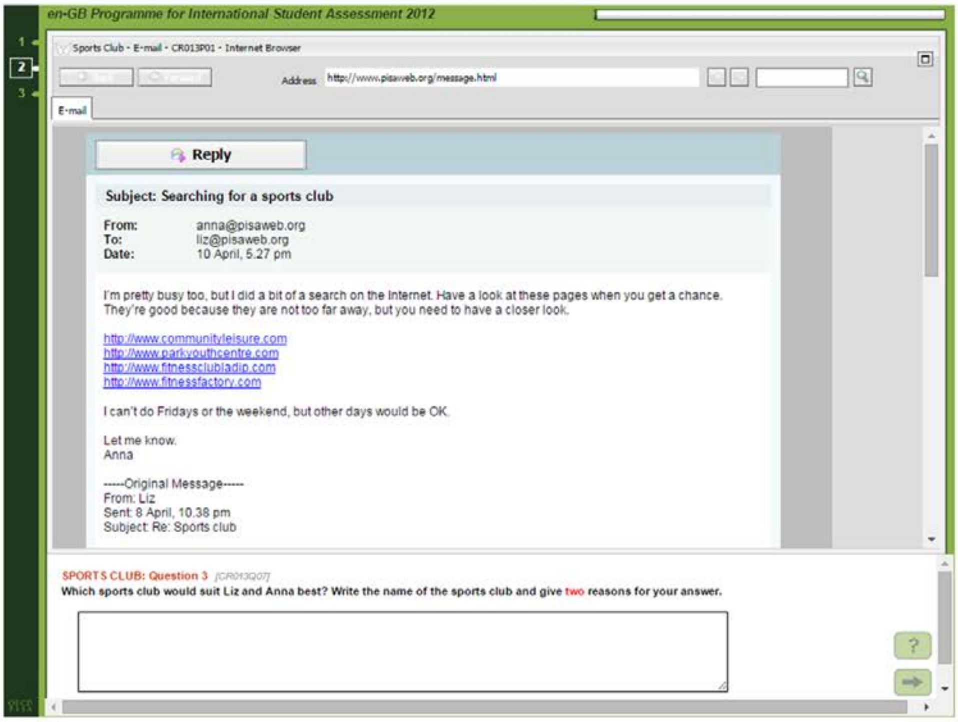


Figure 1. Two examples of digital reading items. The upper part (a) shows the screenshot of an item requesting students to locate the name of a movie from a fictional homepage of the town Seraing. The lower part (b) shows the screenshot of an item requesting students to give a recommendation based on information from an email exchange and the web pages of four fitness studios.

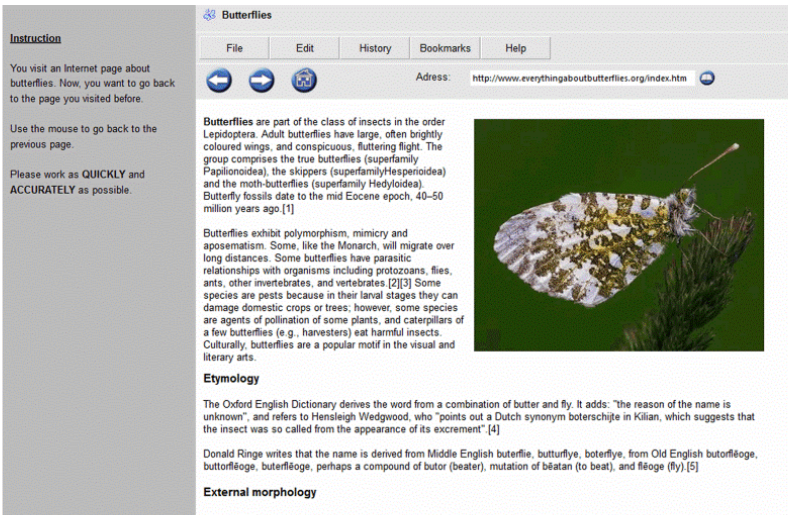


Figure 2. Example of a basic computer skill item: Using a back button. See Appendix D for references on text and artwork.

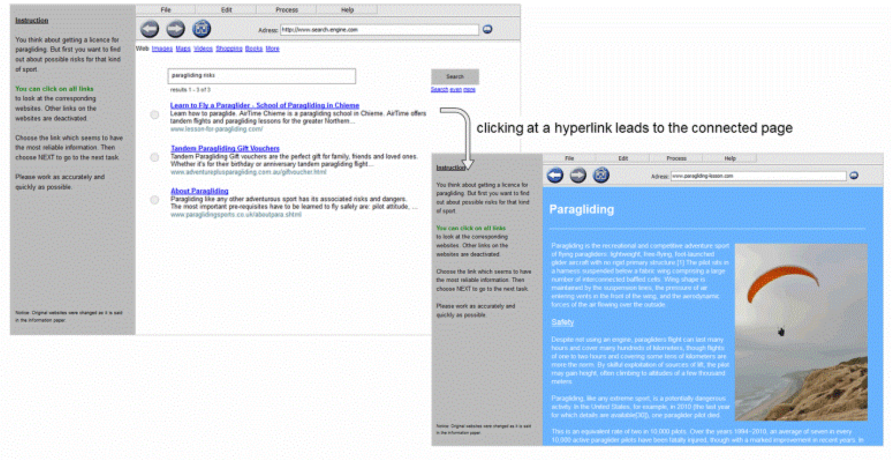


Figure 3. Example of an item measuring evaluating online information: Paragliding risks. See Appendix D for references on text and artwork.

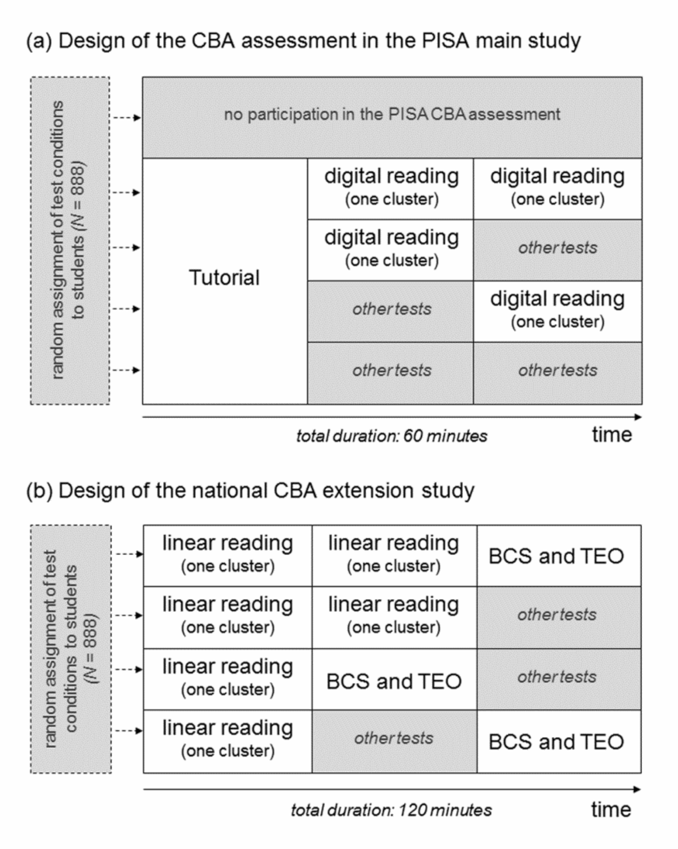


Figure 4. Schematic overview of the design and timeline of (a) the computer based assessment (CBA) in the PISA main study and (b) the national CBA extension study. BCS = Basic Computer Skill Scale. TEO = Test for Evaluation of Online Information.

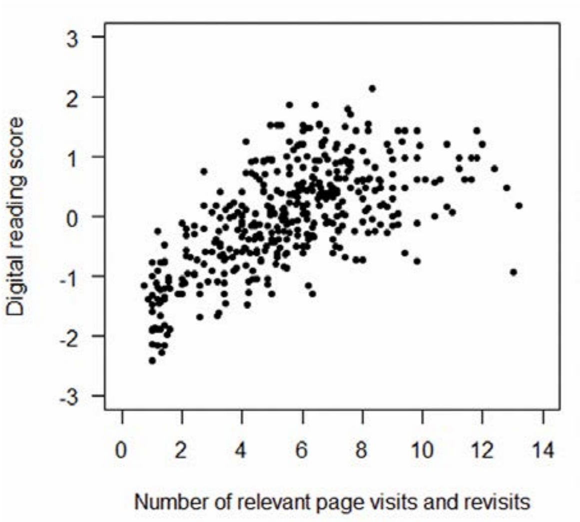


Figure 5. Scatter plot of students' digital reading performance and the number of relevant page visits.

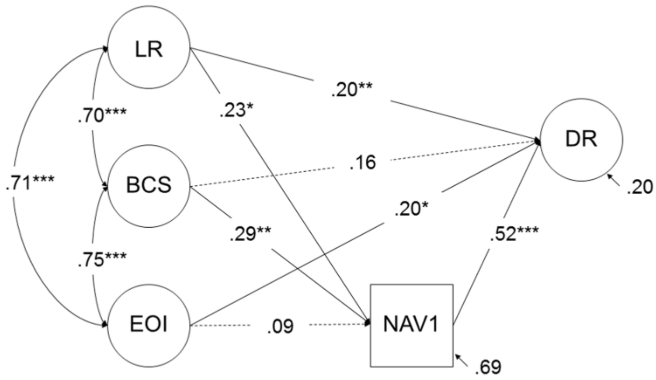


Figure 6. Estimated mediation model with standardized regression coefficients. LR = Linear reading. BCS = Basic computer skills. EOI = Evaluating online information. NAV1 = Number of relevant page visits. DR = Digital Reading. Solid arrows describe significant paths; dashed arrows describe non-significant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