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Epistemological beliefs and self-regulated learning with hypertext

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Abstract This study investigated the relationship between epistemological beliefs, prior domain knowledge and self-regulated learning. Biology students (n=25) and humanities students (n=26) who varied in their epistemological beliefs learned with a hierarchical hypertext about the topic of genetic fingerprinting. During their learning processes, logfiles and questionnaire data were collected. Results indicate that students do metacognitively calibrate their learning process to the complexity of the presented learning material, e.g. by processing more complex deeper-level nodes longer. Furthermore, these calibration processes were significantly related to epistemological beliefs. For example, more 'sophisticated' epistemological beliefs were associated with processing more nodes, whereas more 'naïve' beliefs were related to spending more time on single nodes. Both effects were especially pronounced on deeper hierarchical hypertext levels. Prior domain knowledge also had an impact, especially on comprehensibility ratings: biology students considered all nodes more comprehensible than humanities students. Additionally, epistemological beliefs as well as prior domain knowledge were also significantly associated with the learning outcome: for example, more prior domain knowledge led to significantly higher learning outcome.

Keywords Epistemological beliefs · Metacognitive calibration · Self-regulated learning · Hypertext navigation · Prior domain knowledge

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Epistemological beliefs and learning

During the last years an increasing number of researchers examined effects of learners' epistemological beliefs[1], i.e. learners' beliefs about the nature of knowledge and knowing, on learning processes and outcomes (for overviews, see e.g., Buehl and Alexander 2001; Hofer and Pintrich 1997, 2002). One important theoretical assumption in these fields of research is that learners' epistemological beliefs develop from so called 'naïve'[2] towards 'sophisticated' epistemologies. The term 'naïve' is used to indicate that a person believes, for example, that knowledge is certain, an accumulation of facts and can be transferred (effectively) by a person in a position of authority, like a teacher. By education, people become aware that knowledge is, for example, more complex and relative thus resulting in a focus on the evaluation of different viewpoints (e.g., King and Kitchener 2002). Persons with this so called 'sophisticated' perspective believe, for example, that knowledge is relative, contextual and a complex network. They accept uncertainty and changeability of truth and the notion that knowledge is rather construed than 'given'. Thus, epistemological beliefs encompass different dimensions all relevant for establishing the validity of knowledge claims, in other words, about the very possibility of knowledge (Bromme et al. in press; Rozendaal et al. 2001; Trautwein and Lüdtke in press). Most approaches subsume beliefs about the certainty of knowledge (i.e. if one sees knowledge as certain facts or tentative claims), about the source (for example omniscent authorities), about the structure and about the justification of knowledge.

An increasing number of empirical studies shows that more 'sophisticated' epistemological beliefs are related to more adequate learning strategies and better learning outcomes in traditional classrooms: for example college students' epistemological beliefs are related to their processing of information (e.g., Schommer 1990), academic performance (e.g., Schommer 1993), conceptual change (e.g., Mason and Boscolo 2004), cognitive processes during learning (e.g., Kardash and Howell 2000), and engagement in learning (e.g., Hofer and Pintrich 1997). There are some studies concerning computer-based learning environments as well: epistemological beliefs are related to learning processes and outcomes with hypertext (Bendixen and Hartley 2003; Jacobson et al. 1996; Jacobson and Spiro 1995). For example, Windschitl and Andre (1998) found that students with more 'sophisticated' beliefs learned more with constructivist simulations than students with 'naïve' epistemological beliefs. Bartholomé et al. (2006) as well as Bromme and Stahl (2003) found that students with more 'sophisticated' beliefs showed a more adequate help-seeking behavior within an interactive learning environment. There is also evidence that epistemological beliefs effect students' information retrieval from the Internet (Braten et al. 2005; Hofer 2004).

Thus, on the one hand empirical evidence shows the importance of epistemological beliefs for learning; on the other hand theoretical assumptions on the way epistemological beliefs exactly exert their influence on learning processes are rare. To answer this question, some

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[1] We will consistently use the term 'epistemological beliefs' in this article to refer to beliefs about the nature of knowledge and knowing. Notwithstanding the different notions for the whole construct or special facets of it used in the literature, e.g. reflective judgment (King and Kitchener 2002), epistemological reflection (Baxter Magolda 2004), or epistemological resources (Hammer and Elby 2002), we find it appropriate to subsume them under this widespread term.

[2] These terms (i.e., 'naïve' and 'sophisticated') are commonly used in the epistemological beliefs literature. To make it easier to interpret our view and findings, we decided to retain this terminology. We would like to underline that in our view it should not imply any possible unfortunate and overbearing connotations attached to these terms.

assumptions about the cognitive architecture of epistemological beliefs are necessary. In some models, epistemological beliefs are described in relation to metacognition. Consistently, epistemological beliefs are discussed as an abstract level above a metacognitive level, i.e. epistemic cognition (Kitchener 1983), on a level of 'meta-knowing' about knowledge and knowing, i.e. epistemological meta-knowing (Kuhn 2000), or as epistemic components in an expanded model of metacognition (Hofer 2004). Such models are promising but far from complete. The COPES-model (Winne and Hadwin 1998) locates epistemological beliefs within a system of metacognitive structures for self-regulation and it specifies a functional relationship between epistemological beliefs and learning. Based on this theoretical framework, we want to add to a deeper understanding of the interaction between epistemological beliefs and metacognitive processes by analyzing their impact on learning processes on a detailed level.

COPES-model of self-regulated learning

According to the COPES-model (e.g., Winne and Hadwin 1998, see Fig. 1 for visualization), self-regulated learning occurs in four weakly sequenced and recursive stages: (1) task definition, (2) goal setting and planning, (3) enactment and (4) adaptation. In the task definition stage (1), a student generates her own perception about what the studying task is, and what constraints and resources are in place. Consequently, the student generates idiosyncratic goals and constructs a plan for addressing that study task (2). In the enactment stage (3) the previously created plan of study tactics is carried out. The adaptation stage (4) pertains to fine-tuning of strategies within the actual learning task as well as to long-term adaptations based on the study experience.

All four stages are embedded in the same general cognitive architecture. In the centre of this architecture are processes of metacognitive monitoring and controlling that students might use to calibrate their learning process to perceived task demands. If and how such metacognitive calibration occurs depends on five constituents whose acronym gave the model its name: conditions (C), operations (O), products (P), evaluations (E) and standards (S). Conditions pertain to external task conditions or task demands (e.g., nature of the learning task such as task complexity, nature of the learning material such as the complexity of the learning content) as well as to internal cognitive conditions or learner characteristics (e.g., epistemological beliefs, prior domain knowledge). Conditions influence the whole learning process, especially the operations and standards. Operations include all cognitive processes (e.g., tactics, strategies) that learners utilize to solve a learning task. In each learning stage, these operations create internal or external products. These include internal mental (e.g., a mental model of how to solve the task) as well as external products (e.g., an observable behaviour). Students' goals are

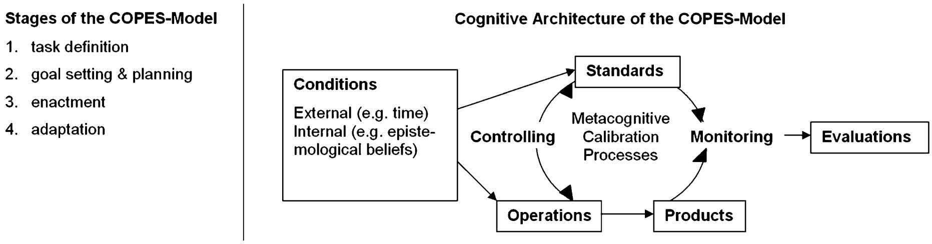

Fig. 1 Visualization of the COPES-model

represented as multivariate profiles of standards. Standards can be described as a profile of different criteria that a student sets for the learning task (e.g., targeted level of understanding, targeted time on task). Evaluations occur during the whole learning process when a student metacognitively monitors her learning process. These evaluations are based on comparisons between the intermediate products on the one hand and her standards on the other. When the student notices discrepancies she is able to perform metacognitive control by executing fix-up operations (e.g., re-reading).

To summarize, the COPES-model describes how students might adapt their self-regulated learning process, e.g. with regard to the complexity of the learning material which constitutes an important external condition for learning. Furthermore, it specifies the impact of learner-related internal conditions such as epistemological beliefs.

Impact of epistemological beliefs on hypertext learning

We assume—in reference to the COPES-model—that epistemological beliefs should influence all stages of self-regulated learning by affecting students' internal standards for metacognitive monitoring and controlling and consequently influencing the processes of metacognitive calibration. In this context, the term calibration is transferred from it's classical application (e.g., Nelson and Dunlosky 1991) to also refer to the alignment between external conditions, i.e. the complexity of the learning material, and students' learning processes, e.g. their reading time of differently complex material. More specifically, we assume that students with more 'sophisticated' epistemological beliefs should be more flexible than students with more 'naïve' epistemological beliefs in adapting their whole learning process (i.e., their task definitions and enactments of strategies according to the COPES-model) to different external conditions such as the demands of the learning content (e.g., complexity of the learning material). Therefore, one possibility to test our assumption is to examine students' adaptation to the demands of the learning material. Note, that this implies that we not necessarily predict a main effect of epistemological beliefs, i.e. more 'sophisticated' beliefs automatically lead to better learning (strategies and outcomes), but rather we predict a potential interaction effect between epistemological beliefs and external task demands. To give an example: on a specific learning task students with 'naïve' and 'sophisticated' epistemological beliefs might not differ at all (e.g., in their perception of a very simple task or in their learning strategies for a very simple learning content); with regard to another task these students might differ significantly (e.g., in their perception of a very complex task or in their learning strategies for a very complex learning content such as deeper hypertext levels). Our argument is analogous to Elby and Hammers (2001) conceptualization of 'sophisticated' epistemologies. They pointed out that it is not very 'sophisticated' to doubt each thesis in each context (e.g., that the earth is (nearly) round), instead they postulate that 'sophistication' entails flexibility or adaptability to contextual demands.

To illustrate this idea, imagine a learner with a naive belief that knowledge is simple and stable. Learners with such 'naïve' epistemological beliefs might interpret a task such as 'to learn' as meaning to 'memorize as many concepts as possible'. According to the COPES-model, epistemological beliefs should directly influence the standards that a learner sets and the operations she employs. Therefore, these 'naïve' learners might set a superficial internal standard for all kinds of learning material (i.e., learning is complete when recall of main concepts is achieved), which in turn is utilized for metacognitive calibration processes. Thus, 'naïve' learners might employ the same superficial learning strategies like memorizing for all kinds of learning material (metacognitive control) and probably might not realize that superficial learning is not sufficient for mastering more complex learning material (metacognitive monitoring). Learners with more 'sophisticated' epistemological beliefs in more uncertain and complex knowledge on the other hand might derive at a more elaborate task interpretation: 'to learn' might be interpreted as 'understand the content in order to be able to apply and evaluate it'. Furthermore, these more 'sophisticated' learners might be more flexible in their epistemological judgments concerning the nature of diverse learning material and thus also in their internal standards. Very simple learning material may elicit slightly more elaborate standards than those of the 'naïve' learners described above (e.g., learning is complete when newly acquired concepts are linked to prior domain knowledge). Nonetheless, the overt behavior may not differ much from that of more 'naïve' learners. For more complex learning material on the other hand, more 'sophisticated' learners might possess much more elaborate standards (e.g., learning is complete when different pieces of information are related to one another and critically evaluated from multiple perspectives). Therefore, 'sophisticated' learners also might differ in overt behavior from more 'naïve' learners, e.g. they might try to access multiple information sources to better evaluate the presented information. To summarize, we hypothesize, that learners with more 'sophisticated' beliefs should be better in calibrating or adapting their learning process to task demands such as the complexity of the learning material, while more 'naïve' learners should be less flexible.

We started to investigate this issue in detail with a series of studies (e.g., Stahl et al. 2006). In all studies the learning content concerns genetic fingerprinting. In this study as well as in subsequent studies, we use a hypertext as a learning environment to examine the functional relationship between epistemological beliefs and learning. This hypertext was designed to explore the question of students' calibration to the learning material: three hierarchical hypertext levels that contain learning material of different complexity were implemented (for more details see below). Thus, the COPES-model would predict that learners with different epistemological beliefs would differ in their calibration to these different demands of the learning material, mediated by their different internal standards. More specifically, we predict that students would calibrate to the differently complex hypertext levels on three variables capturing their learning process: their reading time (calibration of Average Processing Duration per Nodes, APDN), their coverage of content (calibration of Percentage of Processed Nodes, PPN), and their judged comprehensibility (calibration of Average Comprehensibility Ratings, ACR).

Furthermore, in this study we asked students of biology and humanities to learn with our hypertext. We chose to include different levels of prior domain knowledge because this learner characteristic is also considered an important internal condition within the COPES-model (Winne and Hadwin 1998). Furthermore, its impact on computer-supported learning was consistently found in empirical studies (e.g., see Michell et al. 2005).

The objective of this study was to examine two explorative research questions that were deduced from the COPES-model. Our first question is: (1) are learners' epistemological beliefs and their prior domain knowledge related to the learners' calibration processes? In terms of the COPES-model: are learners' with different internal conditions (focus of our study: epistemological beliefs and prior knowledge) differently flexible in adjusting their whole learning process, for example their operations (captured by APDN and PPN) and their evaluations (captured by ACR) to the differential complexity of the learning material (i.e., to different external conditions)? The second question is: (2) do epistemological beliefs and prior domain knowledge influence the learning outcome (in terms of the COPES-model: the product of learning)? Because of the supposedly different strategies enacted by learners with different epistemological beliefs and different prior domain knowledge during hypertext learning, we assume they also should come to different learning outcomes.

Materials and methods

Participants

Fifty-one students participated and received 15 € as reimbursement. The mean age was 23.1 years (SD=2.5). Twenty-five students (13 males and 12 females) on average studied in the fifth (SD=1.0) semester biology or related majors. Their background knowledge was confirmed by the results of a short molecular biology knowledge test (eight points maximum; $M=7.7$, SD=0.7). The other 26 students (10 males and 16 females) on average studied in the sixth (SD=3.9) semester psychology or other humanity majors. The knowledge test revealed minimal background knowledge (eight points maximum: $M=2.8$, SD=1.7). Later on, we had to exclude two humanities students from all further analyses because they did not comply with the instructions. The difference in prior domain knowledge between students of biology and humanities was significant with regard to the knowledge test ($t\ (49)=-13.23$, $p<0.001$). Thus, prior domain knowledge as indicated by group affiliation will be used as dichotomous predictor variable in all subsequent statistical analyses.

Materials

Epistemological beliefs questionnaires Epistemological beliefs were measured by two questionnaires; in both cases the epistemological beliefs factors were used as predictor variables in all subsequent analyses. The instrument of Wood and Kardash (2002) that we labeled WKI (Wood and Kardash Instrument) measures students' general beliefs about the nature of knowledge and knowing. There are some controversies about the adequate conceptualization and measurement of epistemological beliefs: although most researchers agree on a multidimensional conceptualization, the number and kind of these dimensions is discussed controversially (e.g., Hofer and Pintrich 1997). Furthermore, the proposed dimensions could not always be replicated empirically (e.g., Clarebout et al. 2001). Due to these discussions we excluded all items of dimensions that did not pertain to epistemology in a strict sense from the WKI, i.e. most items from the dimensions 'characteristics of successful students' and 'speed of knowledge acquisition'. Thus, we maintained 28 of 38 items that made up the original five factors (Wood and Kardash 2002). The second questionnaire, the CAEB (Connotative Aspects of Epistemological Beliefs; Stahl and Bromme in press), measures students' beliefs referring to the domain of genetics. The CAEB was designed as a semantic differential but with epistemology related adjectives. Thus, the students had to judge 24 pairs of adjectives such as "structured–unstructured" on a seven-point scale.

Hypertext The students in this study had to learn about the topic of mtDNA analysis, a special case of genetic fingerprinting only applicable to the human mitochondrial genome. This content was presented in a hypertext. In general, hypertexts consist of pages (so-called nodes) and connections between pages (so-called links). The specific hypertext used in this study encompasses two parts, an introduction and a main part. The 8-node introduction provides students with general background knowledge in molecular genetics necessary to understand the main topic of mtDNA analysis (e.g., information about the structure of DNA). All students were instructed to read this introduction first. Figure 2 on the other hand visualizes the main part of the hypertext that consists of thirty-one nodes and explains the specific topic of mtDNA analysis. Fourteen of these nodes are arranged in a hierarchical structure (squares in Fig. 2). Deeper levels within this structure are more detailed, specific and contain more instructional figures and references, i.e. present more complex content.

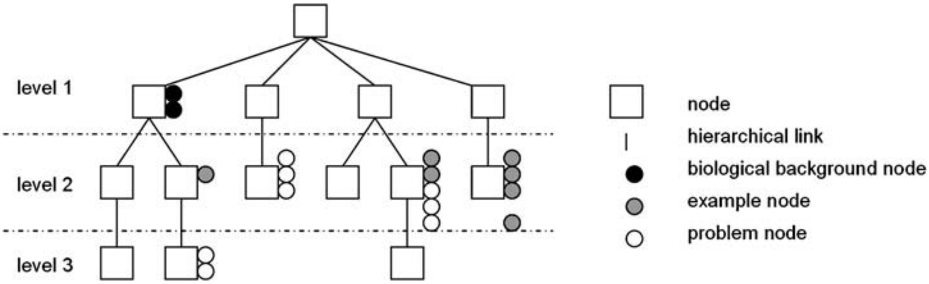

Fig. 2 Visualization of the main part of the hypertext

The top two levels encompass five easy-to-comprehend nodes, one overall introductory node for mtDNA analysis and four introductory nodes for the sub-topics (1) ‘basic idea of mtDNA analysis’, (2) ‘execution of mtDNA analysis in the lab’, (3) ‘interpretation of mtDNA analysis results’ and (4) ‘implementation of mtDNA analysis’. These nodes are short and serve as introductions for novices, thus these two levels are combined in all analyses into the ‘level 1’. The ‘level 2’ contains six nodes of intermediate difficulty that elaborate information on the four sub-topics. The ‘level 3’ contains three nodes with very detailed information on certain aspects of these sub-topics. Consequently, the complexity of the hierarchical hypertext levels varies systematically and these hierarchical hypertext levels can be considered an important external task demand to which students can calibrate their whole learning process. Besides this hierarchical structure, the main part of the hypertext contains 17 nodes in the so-called appendices which are thematically linked with the main text (circles in Fig. 2). These nodes contain additional information about more ‘biological background’ (two nodes), specific case ‘examples’ (seven nodes) and ‘uncertainties/problems’ of mtDNA analysis (eight nodes) and differ in length as well as difficulty. These nodes are linked thematically with their base pages, i.e. those pages that contain related content (symbolized by the circles that are attached to the squares in Fig. 2). Readers can traverse this hypertext any way they want. Hierarchical links lead to subordinate or superordinate nodes (lines in Fig. 2) as well as to the adjacent nodes on the left and right side. Furthermore, readers can directly access even more distant nodes, for example by using the table of content for navigation.

Technically, this hypertext was created with MetaLinks (Murray 2003), an authoring software for hierarchical hypertexts. This software is FileMaker based, uses Netscape Navigator as a browser and collects logfile data automatically. These logfiles indicate students’ hypertext navigation. In the subsequent analyses students’ calibration with regard to the hierarchical hypertext levels was investigated by considering this navigational data, i.e. by comparing it between hypertext levels. More specifically, two variables were computed from these logfiles for each hypertext part (e.g., the three hierarchical levels): (1) Average Processing Duration per Node (APDN—total time spent on a specific hypertext part divided by number of processed nodes in that part) and (2) Percentage of Processed Nodes (PPN—number of processed nodes per part divided by number of existing nodes in that part).

Comprehensibility ratings Students had to judge the comprehensibility of each node they processed during hypertext learning on a seven-point scale (ranging from 1=very comprehensible to 7=very incomprehensible). These ratings indicate their comprehension monitoring. In the subsequent analyses students’ calibration with regard to the hierarchical hypertext levels was investigated by considering their comprehension ratings as third dependent variable (3), i.e. by comparing their Average Comprehensibility Ratings (ACR) between different hypertext levels.

Knowledge tests Eight multiple-choice questions were developed with the help of a domain expert to test students' prior domain knowledge (i.e., molecular prior knowledge test, Cronbach's $\alpha = 0.90$, sample item: "What is the meaning of the abbreviation PCR?"). To measure how much students learned about the topic of mtDNA analysis after they navigated through our hypertext, 15 node-specific multiple-choice questions were developed. Each of these questions pertained to a main concept explained in one of 15 randomly selected corresponding hypertext nodes (i.e., mtDNA analysis knowledge test, sample item: "What constitutes heteroplasmy of the mtDNA?"). However, as students were allowed to traverse the hypertext at free will, not all students accessed all 15 nodes necessary to answer all multiple-choice questions correctly. In order to accommodate this navigation behaviour, an additional category was added to these multiple-choice questions, i.e. "I don't know the answer." Due to this format as well as due to the different difficulty of multiple-choice items in this test (i.e., as they referred to differently complex content from different hierarchical hypertext levels), the internal consistency of this scale was quite low with Cronbach's $\alpha = 0.60$. Students' answers to these questions were assumed to capture their learning outcome and were used as dependent variable in subsequent analyses.

Procedure

Students worked in sessions lasting about 2 h with a maximum of six students per session. During the session each student first completed questionnaires on demographics, epistemological beliefs and prior knowledge in molecular biology. Then all students were introduced to the structure and navigational options of the hypertext. Afterwards, they were instructed to read the eight-node introduction first and subsequently to 'learn as much as possible' about the topic of mtDNA analysis. We explicitly chose such an unspecific learning task to investigate their task interpretation as indicated by their spontaneous navigation of the hypertext. During this task they also had to give comprehensibility ratings for each node they read. After 1 h of working with the hypertext the students completed the knowledge test on mtDNA analysis.

Results

We define ($p < 0.05$) as significant. Furthermore, because of the rather explorative character of the study, we also interpret effects with $p < 0.10$ as trends.

With regard to epistemological beliefs, we decided to calculate factor analyses even with this small sample size because of our revision of the WKI. The factor solution for the WKI encompassed two factors labeled 'simplicity' (nine items, Cronbach's $\alpha = 0.69$) and 'certainty' (five items, Cronbach's $\alpha = 0.73$) which explained 39% variance. The factor 'simplicity[3]'

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[3] Seven of the items of the factor 'simplicity' from the WKI stem from the original factor 'structure of knowledge' (i.e., items 1, 3, 4, 5, 7, 8, 11, cf. Table 12.1 in Wood and Kardash 2002, p. 247). These are supplemented by one item from the original factor 'characteristics of a successful student' ("Successful students understand things quickly.") and one item form the original factor 'speed of knowledge acquisition' ("Most words have one clear meaning.").

measures whether students assume that knowledge is an accumulation of facts versus a complex network of interrelated concepts (sample item: “Most words have one clear meaning.”). The students in this study tended to believe slightly more in simple knowledge (M=4.6, SD=0.8; on a seven-point scale from 1 = knowledge is seen as complex to 7 = knowledge is seen as simple.). Students of biology and humanities students did not differ on this factor. The factor ‘certainty[4]’ refers to students’ beliefs in absolute and exact versus tentative knowledge (sample item: “Today’s facts may be tomorrow’s fiction.”). Students believed more in uncertain knowledge (M=5.9, SD=0.7; on a 7-point scale from 1= knowledge is seen as certain to 7 = knowledge is seen as uncertain). Students of biology and humanities students did not differ on this factor.

The factor solution for the CAEB comprised the two original factors, ‘texture’ (11 items, Cronbach’s α=0.81) and ‘variability’ (9 items, Cronbach’s α=0.80) and explained 41% variance. The factor ‘texture’ encompasses beliefs about the structure and accuracy of knowledge in the domain of (molecular) genetics and ranges from beliefs that knowledge is exact and structured to beliefs that it is unstructured and vague (sample items: “structured–unstructured”, “definite–ambiguous”, “exact–vague”). The biology students tended to believe more in structured knowledge than the humanities students ($F(1, 47)=3.7$, $p=0.06$; biology students: M=3.15, SD=0.71; humanities students: M=2.77, SD=0.68; all ratings on a seven-point scale from 1=unstructured to 7=structured). The factor ‘variability’ encompasses beliefs about the stability and dynamics of domain knowledge and ranges from beliefs that knowledge is dynamic and flexible to beliefs that it is stable and inflexible (sample items: “dynamic–static”, “open–closed”, “temporary–everlasting”). The students of this study tended to believe in relative knowledge (M=4.8, SD=0.8, on a seven-point scale from 1 = absolute to 7 = relative). Students of biology and humanities students did not differ on this factor.

Correlational analysis of these factors revealed two significant relations: the WKI factor ‘simplicity’ was significantly related to the CAEB factor ‘texture’ ($r=-0.29$; $p=0.04$). Students who believed in simple knowledge in general also believed in structured knowledge in genetics. Furthermore, the correlation between the two domain-related factors of the CAEB ‘texture’ and ‘variability’ was significant ($r=0.43$; $p<0.01$). Students who believed in unstructured knowledge in genetics also believed in relative knowledge in genetics.

Are learners’ epistemological beliefs and prior domain knowledge related to their calibration processes?

We detected that students systematically calibrated their learning to the different levels of the hypertext hierarchy containing differently complex learning material. Furthermore, these calibration processes were impacted by students’ epistemological beliefs as well as by their prior domain knowledge. Subsequently, the corresponding results will be presented in detail. In order to investigate this question statistically, we computed three dependent variables for each hypertext part (cf. method section): (1) average processing duration of nodes (APDN) and (2) percentage of processed nodes (PPN) characterize students’ hypertext navigation

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[4] Three of the items of the factor ‘certainty’ from the WKI stem from the original factor “knowledge construction and modification” (i.e., items 1, 6, 11; cf. Table 12.1 in Wood and Kardash 2002, p. 248). These are supplemented by two items from the original factor ‘speed of knowledge acquisition’ (i.e., items 3, 6; cf. Table 12.1 in Wood and Kardash 2002, p. 246).

Table 1 This table lists all means (M) and standard deviations (SD) of the dependent variables that characterize hypertext navigation and comprehension monitoring for all hypertext parts

	M	SD
Level 1 (n=49)		
APDN	01:46	00:38
PPN	95.10	13.86
ACR	1.41	0.62
Level 2 (n=47)		
APDN	03:21	00:53
PPN	87.23	20.33
ACR	2.00	0.76
Level 3 (n=43)		
APDN	03:35	01:27
PPN	85.27	23.35
ACR	2.59	1.17
Biological background (n=14)		
APDN	02:09	00:43
PPN	78.57	25.68
ACR	1.75	0.89
Examples (n=22)		
APDN	01:58	00:38
PPN	48.70	30.75
ACR	1.96	1.17
Problems (n=17)		
APDN	01:50	00:45
PPN	57.35	28.66
ACR	2.03	0.87

APDN average processing duration per node; *PPN* percent of processed nodes; *ACR* average comprehensibility rating

behaviour and students' (3) average comprehensibility ratings (ACR) indicate their comprehension monitoring.

Descriptive results To give an overall idea of students' hypertext navigation, the descriptive values for all hypertext parts are displayed in Table 1. Students on average spent 38 min in the main hypertext (SD=8:44 min). During this learning phase students processed on average 16 nodes (SD=5.78). That equals 52% of existing nodes (PPN: SD=18.65%). On average each single node was processed for 2:29 min (APDN: SD=3:32 min). Not all students navigated to all parts of the hypertext. While all 49 students processed nodes on 'level 1', 47 processed nodes on 'level 2' and only 43 students navigated to 'level 3'. The appendices were processed less often: Only 14 students navigated to the 'biological background', 22 students navigated to the 'examples' and 17 students navigated to the 'problem' nodes.

To answer research question one, we calculated a MANCOVA with the three hierarchical hypertext levels as within-subject repeated-measure factor for the three dependent variables APDN, PPN and ACR. Only students who navigated to all three hierarchical levels were included in this analysis (n=43, see above). Prior domain knowledge (i.e. biology students vs humanities students) was included as independent variable. The four epistemological beliefs factors of the WKI and the CAEB served as covariates. All assumptions of this analysis were tested and even though some slight violations occurred we still consider our results valid[5]. Because of the explorative nature of the study we further decided to calculate correlations between the covariates and the dependent variables for all parts of the hypertext separately to validate our results.

Effects of the repeated-measure factor indicate that students in fact calibrated their learning to the different levels of the hypertext hierarchy containing differently complex learning material. The MANCOVA results revealed no multivariate main effect of the repeated-measure factor hierarchical levels. Nonetheless, univariate trends were detected for two of the three dependent variables. Students tended to process nodes on deeper levels longer (APDN: $F(2, 72)=2.6$, $p=0.09$, $\eta_p^2 = .07$) and tended to process a lower percentage of nodes on deeper levels than on higher levels (PPN: $F(1, 52)=3.6$, $p=0.05$, $\eta_p^2 = .09$).

Epistemological beliefs Epistemological beliefs had significant impact on students' calibration to the hierarchical hypertext levels. Subsequently, the corresponding results will be presented for each epistemological beliefs scale separately. In addition, the correlational results concerning the relation between epistemological beliefs and students' hypertext navigation and comprehension monitoring with regard to the appendices will be reported.

MANCOVA results revealed a significant multivariate main effect for the epistemological belief factor WKI 'simplicity' ($F(3, 35)=4.4$, $p=0.01$, $\eta_p^2 = .28$) and a trend for a multivariate interaction between WKI 'simplicity' and level of hierarchy ($F(6, 32)=2.4$, $p=0.05$, $\eta_p^2 = .31$). The main effect was corroborated univariately on all three dependent variables (APDN: $F(1, 37)=7.1$, $p=0.01$, $\eta_p^2 = .16$; PPN: $F(1, 37)=4.1$, $p=0.05$, $\eta_p^2 = .10$; ACR: $F(1, 37)=6.5$, $p=0.02$, $\eta_p^2 = .15$). Students who believed in complex knowledge in general (i.e., 'sophisticated' view) processed single nodes significantly shorter (APDN), tended to process a larger percentage of nodes (PPN) and judged nodes to be significantly less comprehensible (ACR) than their counterparts who believed in simple knowledge (i.e., 'naïve' view). These results are supported by the correlational results: the belief in complex knowledge (WKI 'simplicity') was significantly positively correlated with less comprehensible node evaluation on 'level 2' and 'level 3' (see Table 2). The trend for a multivariate interaction of WKI 'simplicity' was univariately only replicated on one dependent variable (APDN: $F(2, 72)=6.9, p<.01$, $\eta_p^2 = .16$). Students who believed in complex knowledge not only processed nodes on all levels shorter (see main effect above) but this effect also became significantly more pronounced on deeper hierarchical levels (to visualize this effect, the same MANOVA was also computed with a median-split epistemological belief factor WKI 'simplicity', see Fig. 3a). Consistently, correlational results also only reveal a significant negative relation between the belief in complex knowledge (WKI 'simplicity') and average processing duration per node (APDN) on 'level 3', but no such effects of WKI 'simplicity' on 'level 1' or 'level 2' (see Table 2).

MANCOVA results revealed no multivariate effect for the epistemological belief factor WKI 'certainty'. Still, a trend of an interaction between WKI 'certainty' and level of hierarchy

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[5] More specifically, we ensured that the sample size was adequate to detect effects of medium effect size (Stevens 1996) and adequate for our number of covariates (Huitma 1980). Furthermore, we tested the normal distribution of covariates and dependent variables, the independence of covariates and treatment, the homogeneity of variance, and the homogeneity of hyperplanes. Although small violations occurred, we conclude that our results can still be considered valid (Grimm and Yarnold 1995; Hair et al. 1998; Huitma 1980; Tabachnick and Fidell 2007). To accommodate a small violation of sphericity, we adjusted the degrees of freedom according to Huynh-Feld (cf. Stevens 1996). Because of readability, rounded values will be reported.

Table 2 This table lists all relevant correlations pertaining to research question 1 for all different hypertext parts, i.e. all correlations between the covariates (epistemological belief factors and prior knowledge test score) and the dependent variables that characterize hypertext navigation and comprehension monitoring (APDN, PPN, and ACR)

	WKI simplicity	WKI certainty	CAEB texture	CAEB variability	Knowledge test score
Level 1 (n=49)					
APDN	−0.07	−0.07	.03	−0.19	−0.30*
PPN	−0.19	−0.02	−0.13	0.09	0.15
ACR	−0.20	0.03	0.21	−0.01	−0.40**
Level 2 (n=47)					
APDN	0.09	−0.08	0.09	0.06	−0.32*
PPN	−0.24	0.19	−0.18	0.06	.33*
ACR	−0.33*	−0.14	0.19	−0.09	−0.41**
Level 3 (n=43)					
APDN	.42**	−0.01	0.06	0.14	0.00
PPN	−0.13	0.26***	−0.06	0.14	0.26***
ACR	−0.38*	−0.01	0.29***	0.09	−0.51**
Biological background (n=14)					
APDN	0.19	−0.14	−0.05	−0.15	−0.12
PPN	0.42	0.28	0.18	0.28	0.17
ACR	−0.41	0.08	0.06	−0.28	−0.30
Examples (n=22)					
APDN	0.09	−0.01	0.25	0.06	−0.24
PPN	0.00	−0.12	−0.31	−0.32	0.17
ACR	−0.37***	0.05	0.43*	0.04	−0.26
Problems (n=17)					
APDN	0.22	0.13	0.39	0.56*	0.09
PPN	0.13	0.37	−0.57*	−0.06	0.49*
ACR	−0.29	−0.04	0.17	−0.03	−0.15

APDN average processing duration per node; *PPN* percent of processed nodes; *ACR* average comprehensibility ratings

* $p<0.05$; ** $p<.01$; *** $p<0.10$

was detected univariately (PPN: $F(1, 52)=2.8$, $p=0.09$, $\eta_p^2 = .07$): students who believed in uncertain knowledge in general (i.e., 'sophisticated' view) tended to process an increasingly higher percentage of nodes (PPN) on deeper levels than their more 'naïve' counterparts (to visualize this effect, the same MANOVA was also computed with a median-split

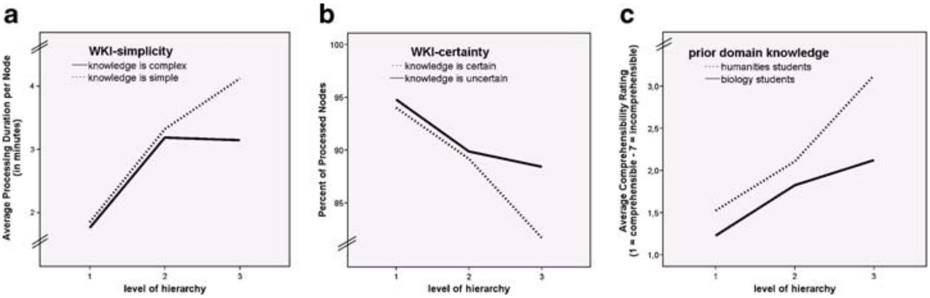

Fig. 3 Visualizations of significant interaction effects concerning research question 1. To visualize the epistemological belief effects, WKI 'simplicity' **a** and WKI 'certainty' **b** were median-split (**c** for prior knowledge, the lines represent the two samples of biology students and humanities students)

epistemological belief factor WKI ‘certainty’, see Fig. 3b). This effect was corroborated by correlational results: the belief in uncertain knowledge (WKI ‘certainty’) tended to be associated with a higher PPN on ‘level 3’, but no such relationship was detected on ‘level 1’ or ‘level 2’ (see Table 2).

MANCOVA results revealed no significant effects for the epistemological belief factors of the CAEB. Nevertheless, the belief in unstructured knowledge in genetics (i.e., ‘sophisticated’ view on CAEB ‘texture’) tended to be correlated with judging nodes on ‘level 3’ less comprehensible (see Table 2).

Table 2 also displays the correlations between covariates and dependent variables that characterize hypertext navigation and comprehension monitoring within the three appendices. ‘Sophisticated’ beliefs in unstructured knowledge in genetics (CAEB ‘texture’) were significantly and beliefs in complex knowledge in general (WKI ‘simplicity’) were associated as a trend with judging nodes in the ‘examples’ less comprehensible. Further significant correlations were found concerning the ‘problem’ nodes: students who believed in unstructured knowledge in genetics (CAEB ‘texture’) processed significantly fewer of these nodes (PPN). Students who believed in relative knowledge in genetics (i.e., ‘sophisticated’ view on CAEB ‘variability’) spent significantly more time on these nodes (APDN). Note that students’ navigation with regard to these problem nodes indicates a reverse pattern than students’ navigation with regard to the hierarchical hypertext levels. These seemingly contradictory effects will be discussed in the discussion section.

Prior knowledge Prior domain knowledge had significant impact on students’ calibration to the hierarchical hypertext levels. MANCOVA results reveal a significant multivariate main effect of prior domain knowledge ($F(3,\ 35)=3.5$, $p=0.03$, $\eta_p^2 = .23$). Univariately, this effect was significantly corroborated only on one dependent variable (ACR: $F(1,\ 37)=7.5$, $p<.01$, $\eta_p^2 = .17$): biology students with more prior domain knowledge significantly judged all nodes to be more comprehensible than humanities students. This effect was supported by correlational results (for these analyses the prior knowledge test score was utilized as indicator of prior domain knowledge instead of group affiliation): more prior knowledge was significantly associated with judging nodes more comprehensible on all three levels (see Table 2). We also found a significant univariate interaction between level of hierarchy and prior knowledge for comprehensibility ratings (ACR): biology students not only judged nodes on all levels more comprehensible (see main effect above), but this effect also became significantly more pronounced on deeper levels ($F(2,\ 74)=4.8$, $p=0.01$, $\eta_p^2 = .12$; see Fig. 3c). Additionally, results of the correlations demonstrated that more prior domain knowledge was also significantly associated with a lower processing duration of single nodes (APDN) on ‘level 1’ and ‘level 2’, with higher percentage of processed nodes (PPN) on ‘level 2’ (significantly) and ‘level 3’ (trend), and with a significantly higher percentage of processed ‘problem’ nodes (see Table 2).

Do epistemological beliefs and prior domain knowledge influence the learning outcome?

We found significant effects of epistemological beliefs and prior domain knowledge on the learning outcome. Subsequently, the corresponding results will be presented in detail. In order to investigate this question statistically, multiple indicators of learning outcome were computed. In this study the students had free choice where to navigate in the hypertext to ‘learn as much as possible’ about the topic mtDNA. Nonetheless, all students had to answer the same multiple choice questions to measure their learning outcome. Therefore, we calculated not only the total test score of the mtDNA knowledge test as dependent variable, but also two sub-scores: the percentage of correctly answered questions pertaining to processed nodes (PP= percentage when processed) shows how much students recall the information they had in fact read. Furthermore, the percentage of correctly answered questions pertaining to non-processed nodes was calculated (PNP—percentage when not processed). We calculated an ANCOVA with prior domain knowledge (i.e., biology students vs humanities students) as independent variable and the four epistemological beliefs factors as covariates for the total test score. Furthermore, we calculated a MANCOVA with the same variables for the two sub-scores PP and PNP. All assumptions of these analyses were tested and no violations were detected.

Descriptive results On average students answered 58% of the 15 questions about mtDNA analysis correctly (M=8.76; SD=2.43). When they processed the corresponding node previously (PP), they answered 86% (SD=15.09%) correctly. When they did not process the associated node previously (PNP) they answered 26% (SD=18.33%) correctly.

Epistemological beliefs Epistemological beliefs impacted the learning outcome. The ANCOVA revealed a trend of a main effect for WKI ‘simplicity’ on the total test score ($F(1, 43)=3.4$, $p=0.07$, $\eta_p^2 = .07$). Students who believed in complex knowledge (i.e., ‘sophisticated’ view) tended to score higher on the mtDNA knowledge test. No effects for epistemological beliefs were detected in the MANCOVA for the two sub-scores.

Prior knowledge Prior domain knowledge had significant impact on the learning outcome. The ANCOVA revealed a significant main effect of prior knowledge on the total test score ($F(1, 43)=8.3$, $p=0.01$, $\eta_p^2 = .16$). This effect was corroborated within the MANCOVA multivariately, i.e. a trend of a main effect of prior domain knowledge was detected ($F(2, 42)=2.5$, $p=0.09$, $\eta_p^2 = .11$), but univariately only a significant main effect on the sub-score for the non-processed nodes was found (PNP: $F(1, 43)=4.9$, $p=0.03$; $\eta_p^2 = .10$). In all cases, biology students with more prior domain knowledge scored higher on the mtDNA knowledge test. Significant correlations and trends between the molecular biology test that was administered before hypertext learning and the mtDNA knowledge test to measure learning outcome supported this effect (with total score: $r=0.56$, $p<0.01$; with PP: $r=0.27$, $p=0.07$; with PNP: $r=0.27$, $p=0.06$).

Discussion

This article presents a study that is part of a more comprehensive research project to examine the effects of epistemological beliefs on metacognitive calibration during learning processes within a complex hypermedia system. Starting from the COPES-model (Winne and Hadwin 1998) we plan to examine the effects of students’ epistemological beliefs on learning processes in detail. In this exploratory study students navigated through a small hypertext (31 nodes) with the rather unspecific goal to ‘learn as much as possible’. Keep in mind that all presented results should be interpreted with due caution: this study was designed as a first exploration of the research questions with a small sample size and furthermore we interpreted effects starting at alpha <0.10. Thus, the generalizability of these results might be limited and we explicitly accepted the risk of finding small effects which might not usually be considered statistically significant. In the subsequent sections, first the results of the two main research questions will be discussed. Subsequently, open issues and suggestions for further research will be addressed and some tentative implications will be drawn.

Are learners' epistemological beliefs and prior knowledge related to their calibration processes?

We found evidence that students do calibrate their learning to the different levels of the hypertext hierarchy containing differently complex learning material and that this calibration is effected by their epistemological beliefs and prior domain knowledge.

Students processed the three different hierarchical hypertext levels differently and thus showed some degree of metacognitive calibration to the underlying complexity of the learning material: nodes on deeper levels were processed longer and a lower percentage of nodes was processed on deeper levels. This result is consistent with the assumptions of the COPES-model (Winne and Hadwin 1998), i.e. that external conditions such as the complexity of the learning material influence students' learning processes. The validity of this finding is further supported by consistent results from other empirical studies that demonstrate that in general learners do not learn equally (well) from texts differing in their complexity, e.g. from intact texts versus texts with deleted letters (Maki et al. 1990), from texts varying in their Flesch scores (Weaver and Bryant 1995), or from texts varying in coherence (McNamara et al. 1996).

Concerning the impact of epistemological beliefs, we will first shortly review the effects for each epistemological beliefs factor separately before discussing the whole pattern of effects. With regard to the epistemological belief factor WKI 'simplicity' we found that students who believed in complex knowledge (i.e., 'sophisticated' view) processed a larger percentage of nodes across all levels. On the other hand, these students processed nodes on all levels shorter, and this effect becomes more pronounced on deeper levels, especially on 'level 3'. Furthermore, students who believed in complex knowledge (i.e., 'sophisticated' view on WKI 'simplicity') judged nodes to be less comprehensible across all levels. With regard to the epistemological belief factor WKI 'certainty' we found that students who believe in uncertain knowledge (i.e., 'sophisticated' view) processed an increasingly higher percentage of nodes on deeper levels, especially on 'level 3'. With regard to the domain-related CAEB factors no significant MANCOVA effects were found. Still, correlations demonstrate that the belief in unstructured knowledge (i.e., 'sophisticated' view on CAEB 'texture') is associated with judging nodes on deeper levels less comprehensible. We also found significant correlations between the CAEB factors and the dependent variables within the appendices (i.e., 'biological background', 'examples' and 'problems'). For example, students who displayed more 'sophisticated' beliefs also processed a lower percentage of nodes about problems (CAEB 'texture') but processed each of these node longer (CAEB 'variability').

Considering all effects of epistemological beliefs together, we summarize that these effects are in accordance with the COPES-model (Winne and Hadwin 1998). First, because they indicate that the internal condition of epistemological beliefs in fact has an impact on learning processes as assumed in the COPES-model. More specifically, as predicted epistemological beliefs exerted a direct influence on students' operations (i.e., captured by APDN and PPN) as well as on their internal standards (i.e., indirectly captured by their ACR). Second, we inferred from the COPES-model that epistemological beliefs should exert a stronger influence on learning more complex material than on learning simple material, i.e. we predicted not only main but also interaction effects for this internal condition. The empirical results support this prediction. However, we also predicted that 'sophisticated' epistemological beliefs should be associated with stronger calibration to the complexity of the learning material than 'naïve' beliefs. The detected interaction effects with the hierarchical hypertext levels counterintuitively indicate reverse results: more 'sophisticated' beliefs were consistently associated with processing more nodes, especially on 'level 3' (effect of WKI 'certainty' on PPN), and with processing single nodes shorter on all hierarchical levels, especially on 'level 3' (effect of WKI 'simplicity' on APDN). Thus, in both cases 'naïve' students calibrated stronger to the complexity of the learning material, i.e. indicated by a steeper incline of their values between the three hierarchical levels (cf. Fig. 3a and b). The validity of all of these results is supported by consistent results from other empirical studies and even the apparently counterintuitive results of this study can be explained by referring to these other results. Epistemological beliefs were often detected to have a significant positive impact on learning processes and outcomes, e.g. on hypertext navigation strategies that could be considered operations in the terms of the COPES-model (e.g., Bendixen and Hartley 2003; Jacobson and Spiro 1995) as well as on students' internal standards corresponding to standards in the term of the COPES-model (e.g., Schommer 1990). To give a more specific example of the latter: Wood and Kardash (2002) found that more 'sophisticated' students applied more strategies to develop awareness. Such application of superior awareness strategies might also be indicated by 'sophisticated' students' more critical node evaluation in this study (effects of WKI 'simplicity' and CAEB 'texture'on ACR). Probably 'sophisticated' students judged comprehensibility in terms of an elaborate critical internal standard in mind, e.g. deep understanding, whereas 'naïve' students might have been satisfied with understanding single facts without considering their interrelations, i.e. they might have had a more superficial standard in mind. Furthermore, considering that more 'sophisticated' epistemological belief are in general also associated with more beneficial learning strategies, i.e. operations captured by APDN and PPN in this study, this might explain the partly counterintuitive results, e.g. that 'naïve' students calibrated stronger to the complexity of the learning material. For the task 'to learn as much as possible' a selective reading strategy (e.g., Reynolds 1992) might have been more beneficial than trying to comprehend and memorize every detail, i.e. to strongly calibrate to the complexity of the learning material. Thus, 'sophisticated' students in this study who believe in complex and uncertain knowledge might have tried to get an overview by processing as many nodes as possible (cf. effects of WKI 'simplicity' and WKI 'certainty' on PPN) in order to understand the most important concepts and their interrelations. Additionally, these 'sophisticated' students might have selectively focused their attention especially on content that allowed for judging the relevance and validity of the presented information in the remainder of the hypertext (cf. effects of CAEB 'texture' on PPN and CAEB 'variability' on APDN within the problem nodes). More 'naïve' students in this study on the other hand who believed in simple and factual knowledge might have attempted to memorize detailed facts, i.e. they might have been seduced by many extraneous details, especially on deeper hierarchical levels (cf. effect of WKI 'simplicity' on APDN). Because these students concentrated on such nodes, they probably ran out of time and were not able to visit more nodes. Consequently, 'sophisticated' students might have been rather driven by task demands and thus did not strongly calibrate to the complexity of the learning material whereas 'naïve' students might have been driven by the demands of the learning material to a higher degree, thus demonstrating better calibration. To give a consistent example from the literature: the results of Bartholomé et al. (2006) indicate that 'sophisticated' students access more context sensitive help nodes during plant identification. The access of more additional information (i.e., more nodes, especially on deeper hierarchical levels) could be interpreted as indicating the same underlying strategy of getting a thorough overview employed by 'sophisticated' students in this study.

Concerning prior domain knowledge, this internal condition according to the COPES-model (Winne and Hadwin 1998) mainly impacted on students' comprehensibility ratings and had almost no impact on students' navigation strategies: biology students with more prior domain knowledge judged nodes across all levels to be more comprehensible (ACR).

This effect became more pronounced on deeper hierarchical levels. Furthermore, higher prior knowledge was associated with shorter processing of nodes on ‘level 1’ and ‘level 2’ (APDN), and processing of more nodes on ‘level 3’ (PPN). These effects are consistent with the predictions of the COPES-model: prior domain knowledge impacted students’ operations (captured by APDN and PPN) as well as their internal standards (indirectly captured by ACR) and these effects were stronger for more complex learning material. Most likely, biology students with more prior domain knowledge were familiar with some of the facts explained in the hypertext. Thus, the nodes were subjectively easier to comprehend (ACR). Probably for the same reason students with more prior domain knowledge were able to faster comprehend the nodes’ content (APDN) and thus were able to access more nodes (PPN). These effects are also consistent with results from other empirical studies. For example, the fact that prior domain knowledge was not equally important for texts of different complexity (cf. interaction effect of prior domain knowledge on ACR in this study, cf. Fig. 3c) was also demonstrated by Salmerón et al. (2006) who manipulated text coherence which can be considered an indicator of complexity and by Calsir and Gurel (2003) who manipulated the complexity of a hypertext by linking it linearly, hierarchical, and in a mixed way. In both examples, prior domain knowledge elicited more effects with more complex (hyper)texts. Furthermore, Rouet et al. (1997) also report similar results with regard to the differential effects of prior domain knowledge: prior domain knowledge did not impact the employed learning strategies (comparable to the small impact of prior domain knowledge on operations in our study) but significantly impacted students’ document evaluation (comparable to the significant impact of prior domain knowledge on students’ comprehensibility ratings in our study).

Do epistemological beliefs and prior knowledge influence the learning outcome?

We found significant effects of epistemological beliefs and prior domain knowledge on the learning outcome.

With regard to epistemological beliefs, students believing that knowledge is complex (i.e., ‘sophisticated’ view on WKI ‘simplicity’) demonstrated higher total learning outcomes than students who believed in simple knowledge. This means that the ‘naïve’ students’ navigational behavior (i.e., taking more time to read the most complex nodes) did not result in more knowledge about the main concepts of the nodes. Instead, the selective reading strategy employed by the ‘sophisticated’ students (i.e., accessing more nodes and reading deep-level nodes more superficially) led to better learning outcome and thus proved to be more beneficial. Most likely, this selective strategy focused exactly on the most relevant concepts that were also required in order to answer the learning outcome questions. This result is in line with the COPES-model (Winne and Hadwin 1998) that predicted that epistemological beliefs would indirectly impact learning outcome. Furthermore, this result is also in line with results from other empirical studies that consistently indicate that more ‘sophisticated’ epistemological beliefs are beneficial for the learning outcome (e.g., Schommer 1990, 1993).

Prior knowledge also affected students’ learning outcome: biology students with higher prior domain knowledge were better able to answer all questions on mtDNA analysis. Nonetheless, there are some hints that these effects are more selective: for questions pertaining to processed nodes (PP) no significant difference between biology and humanities students was detected whereas the difference was highly significant when questions pertaining to non-processed nodes were considered (PNP). Thus, the prior domain knowledge of biology students seems to be especially helpful in compensating for non-processed material. Because of their prior domain knowledge biology students were probably able to infer the right answers from the already processed material of the hypertext and their prior knowledge. These results are consistent with the predictions of the COPES-model (Winne and Hadwin 1998) that this internal condition should impact the learning outcome indirectly. Furthermore, these results are also consistent with results from other empirical studies. For example, Lind and Sandmann (2003) demonstrated that more domain expertise was positively associated with better learning outcome and Ford and Chen (2000) demonstrated the same effect for a hypermedia learning scenario.

Open issues and suggestions for further research

Summarizing the results, epistemological beliefs and prior domain knowledge are both significantly associated with the learning process and the learning outcome within our hierarchical hypertext. Nevertheless, our results have some limitations. More specifically, the following open issues need to be kept in mind when interpreting our results and will be addressed in future research:

First of all, some methodological issues need to be considered. Our students could navigate through the hypertext in a self-determined way. Thus, students could consciously decide to skip some nodes and concentrate on others instead. This selection process is a defining characteristic of learning with complex information systems. Thus, it is very interesting to notice what kind of information is attended and what kind of information is ignored. Nonetheless, it reduces the sample size for analyses, especially with regard to the appendixes that were rarely attended. Furthermore, due to the correlative nature of the study, no causal relationships can be determined. In future studies within our project we will attempt an experimental manipulation of epistemological beliefs to show this kind of causal impact.

A second issue pertains to the question to which degree epistemological beliefs are domain related or independent from the domain they refer to. There is growing evidence that learners have general epistemological beliefs as well as domain related beliefs (e.g. Buehl et al. 2002). But up to now it is unclear how such different levels might interact with each other. Due to this discussion we included one domain general instrument (WKI) and one domain related instrument (CAEB) in our study. Surprisingly, the students' more general beliefs, especially concerning the dimension of 'simplicity' (WKI), had the strongest impact on the calibration processes within the hierarchical hypertext and on the learning outcome. Within the appendices the domain related epistemological belief factors captured by the CAEB had the strongest impact whereas the domain general factors of the WKI almost had no impact. Therefore, it might be that the domain specific epistemological beliefs only become relevant for processes such as critical evaluation (based on the 'problem' nodes) or further elaboration (based on 'examples'). For more general navigational behaviour—that might be less dependent on a specific topic but more on how to handle the structure of the hypertext—the domain general beliefs appear to be more relevant. This might also be true for the 'simple' knowledge test for measuring learning outcome that was limited to the recall of facts. In this case deeper understanding of the presented information (e.g., based on processing of 'examples') or critical evaluation of the information (e.g., based on processing 'problem' nodes) gave no advantages to answer questions about specific facts. This might also change for more complex tasks like writing a pro- and contra-argumentation. Concerning this issue, more research is needed.

Third, so far we only included single unit measures describing the online hypertext navigation (i.e., ADPN and PPN). As there are only few studies investigating the impact of epistemological belief on *online* learning processes we consider this an adequate first strategy. Furthermore, these measures can be easily captured by logfiles. Still, at least two issues have to be kept in mind with these variables: because all students have the same amount of time for learning, the Percentage of Processed Nodes (PPN) and the Average Duration of Processed Nodes (ADPN) are interdependent. Therefore, students could either concentrate on getting an overview by processing as many nodes as possible (high PPN) or concentrate on paying adequate attention to details by spending long time on each node (high ADPN). Interestingly, all effects of epistemological beliefs show the same picture for the hierarchical hypertext: 'sophisticated' beliefs were consistently associated with trying to get an overview (effect of WKI 'certainty' on PPN) and consequently with shorter processing of nodes (effect of WKI 'simplicity' on ADPN). For the appendix about problems the picture is reversed: more 'sophisticated' beliefs were related to longer processing of single nodes (effect of CAEB 'variability' on ADPN) at the cost of processing fewer 'problem' nodes (effect of CAEB 'texture' on PPN). The second issue is that these variables do not capture more detailed hypermedia navigation strategies. Logfiles show that students who display similar values (PPN, ADPN) can still employ very different navigation strategies. For example, one student could start with reading all 'level 1' nodes to get an overview, then continue with reading all information available on the 'basic idea of mtDNA'. Another student could start to go into the details of the 'basic idea' right away and go to the other topics afterwards. More strategies are feasible.

Implications

Because of the above mentioned open issues as well as because of the explorative nature of this study only tentative implications can be drawn. First of all, the results show that students do metacognitively calibrate their learning process to the complexity of the learning material. The texts in the hypertexts were of different complexity. Our students processed complex texts written for learners with a higher level of expertise ('level 3') differently from introductory texts ('level 1'). Furthermore, epistemological beliefs most strongly impacted on processing the more complex, deeper-level nodes or nodes specific to 'problems'. This implies that the use of complex information sources or information sources that allow for critical evaluation requires special attention in educational settings. In these cases students will differ in their processing of information depending on their learner characteristics such as epistemological beliefs and prior domain knowledge. One way to deal with these differences in processing is to provide adequate scaffolding, for example by eliciting an adequate understanding of the task or by stimulating adequate goals for the task (e.g. critical evaluation). As mentioned before, to 'learn as much as possible' could be interpreted in different ways. One perspective would be to try to get an overview of the whole topic by browsing as many nodes as possible. This interpretation would explicitly consider the limited time on task and thus control the learning process with the goal of getting as complete and deep an overview as possible in such a short time. Another interpretation would be to memorize each detail presented. This interpretation would neglect to control for limited time on task and just consider the targeted level of understanding, i.e. memorization of details. In this study, employing a selective reading strategy that was probably based on the first interpretation proved beneficial for the learning outcome. Other interpretations are feasible. Thus, scaffolds for task interpretation might—at least for students with more naive epistemological beliefs or low prior domain knowledge—ameliorate students spontaneous processing of such complex or critical information sources.

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