Epistemological Sensitisation Causes Deeper Elaboration during Self-Regulated Learning

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Abstract: Previous research indicates that students' adaptation to task complexity in the planning stages of self-regulated learning are related to their epistemological beliefs (Stahl, Pieschl, & Bromme, 2006), but it is an open issue if students enact similar strategies in subsequent stages. Based on the COPES-model (Winne & Hadwin, 1998) the impact of epistemological beliefs on learning is tested here experimentally. In this study, students (21 humanities students, 14 biology students) had to solve five tasks of different complexity (Anderson et al., 2001) with a hypertext on "genetic fingerprinting". Results indicate that students adapted their concurrent thoughts and concurrent actions to task complexity in this enactment stage. An epistemological sensitisation was administered that elicited more "sophisticated" beliefs and caused more elaborate learning processes. For example, students with this sensitisation employed more metacognitive planning, especially for more complex tasks. Additionally, effects of prior domain knowledge were investigated.

Introduction

Epistemological Beliefs and Learning

Research on epistemological beliefs, i.e. learners' beliefs about the nature of knowledge and knowing, has expanded considerably in recent years (see, for overviews, Buehl & Alexander, 2001; Hofer & Pintrich, 1997). One important theoretical assumption in this field of research is that learners' epistemological beliefs develop from more "naive" views (knowledge is absolute; knowledge is an accumulation of facts) to more "sophisticated" beliefs (knowledge is relative and contextual, knowledge is a complex network). Additionally, an increasing number of empirical studies shows that such sophisticated beliefs are related to more adequate learning strategies and better learning outcomes. To give some examples from traditional classrooms: College students' epistemological beliefs were related to their processing of information and their monitoring of comprehension (Schommer, 1990), their academic performance (Schommer, 1993), conceptual change (Mason & Boscolo, 2004), and further cognitive processes during learning (Kardash & Howell, 2000). There are fewer studies concerning computer-based learning environments, but their results are encouraging as well. Concerning learning with hypertext, Jacobson and Spiro (1995) found that learners with more sophisticated epistemological beliefs were more able to learn and apply their knowledge after using a hypertext system than students with simpler epistemological beliefs. Bendixen and Hartley (2003) also found that epistemological beliefs are associated with learning outcomes in learning with hypertexts. And Bartholomé, Stahl, Pieschl, and Bromme (2006) 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 are related to students' information retrieval from the Internet (Hofer, 2004).

Despite these positive empirical results some open issues remain: First, the exact relation between epistemological beliefs and learning is still unclear on a theoretical level. Some researchers assume that epistemological beliefs are somehow part of metacognitions (Hofer, 2004; Kitchener, 1983; Kuhn, 2000). However, their models do not specify the functional relationship between epistemological beliefs and learning in detail. Second, most empirical results concerning this relationship are correlative in nature. Thus, it is unclear if sophisticated beliefs cause better learning or if students with better learning strategies automatically develop more sophisticated beliefs. In order to determine causality, experimental studies are needed that test interventions changing students' epistemological beliefs.

COPES-Model of Self-Regulated Learning

The COPES-model (Winne & Hadwin, 1998) provides an encouraging theoretical background that helps to specify a functional relationship, assumes causality, and incorporates epistemological beliefs as an important condition for the whole learning process. This model is well established in recent research (Greene & Azevedo, 2007). According to this model, 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 (about constraints and resources). Based on this definition the student generates idiosyncratic goal(s) 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 optional 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 that can be described by 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 (e.g., task complexity) as well as to internal cognitive conditions (e.g., prior domain knowledge, epistemological beliefs). 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 products (e.g., an essay). Students' goals are represented as multivariate profile of standards. Standards can be described as a profile of different criteria that a students sets for the learning 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 she notices discrepancies she is able to perform metacognitive control by executing fix-up operations.

Based on the COPES-model we hypothesize that epistemological beliefs as well as prior domain knowledge influence all stages of self-regulated learning within a hypermedia learning system, especially students' adaptation to external conditions like task complexity. Epistemological beliefs and prior domain knowledge were selected because of their crucial importance for learning as indicated by the COPES-model. We explicitly focused on students' adaptation to task complexity as an approach to scrutinize affordances of learning, especially those given by the content. To illustrate this for epistemological beliefs imagine a learner with a "naïve" belief that knowledge is simple and stable. As epistemological beliefs directly influence the standards, the learner might probably set quite superficial goals ("The goal is achieved if I can recall all important facts.") compared to a more "sophisticated" learner who believes that knowledge is complex and relative. Epistemological beliefs also directly influence the operations, thus a more "naïve" learner might enact rather superficial operations like memorizing compared to a more "sophisticated" learner who might enact strategies of deeper elaboration. These differences might be negligible for very simple tasks because learners enact similar strategies but might become more pronounced for complex tasks. Consequently, we hypothesize, that learners with more "sophisticated" beliefs should be better in calibrating to task complexity. Within series of coordinated studies we have already tested this hypothesis for the preparatory stages of learning (i.e., task definition, goal setting and planning) and found positive effects (Stahl, Pieschl, & Bromme, 2006). However, because students frequently don't do what they say they do, for example indicated by the lack of congruence between self-report questionnaires and online measurements of self-regulated learning strategies (Jamieson-Noel & Winne, 2003), it could not be taken for granted that students would execute their plans in real learning scenarios as indicated by their goal setting and planning. Thus, it is an open issue if similar effects can be detected in the enactment and adaptation stages. Therefore, the same research questions will be investigated in these stages: (1) Do learners adapt their learning process to task complexity? (2) Are these adaptation processes impacted by epistemological beliefs and prior domain knowledge? And (3) does adaptation impact the learning outcome?

Method

Procedure

This study consists of two sessions: During the first session all students filled in online-questionnaires about their domain-related epistemological beliefs. Based on their responses and their prior domain knowledge, students were sorted into two matched sub-samples that received two versions of the epistemological sensitisation implemented to change students' epistemological beliefs in the second session. Re-administering the epistemological beliefs questionnaires as a treatment-check validated the success of this intervention. Subsequently, students were introduced to navigational options and the structure of a hierarchical hypertext about "genetic fingerprinting". In the main part of the study, students had one hour to solve five learning tasks that systematically differed in complexity with this hypertext. Students' whole self-regulated learning process was captured during this learning phase by multiple measures: Students were prompted in fixed time intervals to elaborate on their concurrent thoughts. Furthermore, detailed logfiles were automatically collected to capture students' concurrent navigation in the hypertext. Additionally, as measures of learning outcome, students' answers to the tasks were analysed.

Participants

Students were selectively recruited to ensure two levels of prior domain knowledge. Fourteen advanced students of biology (4 males and 10 females, mean age 24 years *SD* = 2.46) took part in this study as discipline experts (Rouet, Favart, Britt, & Perfetti, 1997). Their high level of prior knowledge was confirmed by the results of a short knowledge test (8 points maximum; *M* = 7.57, *SD* = 0.65). Twenty-one students of humanities (1 male, 20 females, mean age 21 years *SD* = 1.34) scored lower in the knowledge test (8 points maximum; *M* = 2.52, *SD* = 1.78) and can be considered novices (Chi, 2006). The difference between both sub-samples in the knowledge test was significant: t (33) = 10.14, $p < .001$. Therefore, these quasi-experimental groups will be included as independent variable tapping prior domain knowledge in all subsequent analyses with regard to the impact of internal conditions.

Materials

Epistemological Beliefs Questionnaires

The success of the epistemological sensitisation was determined by administering two domain-dependent questionnaires before and after this intervention. The CAEB (Connotative Aspects of Epistemological Beliefs; Stahl & Bromme, in press) consists of two scales of connotative adjective pairs: CAEB-texture measures beliefs about the structure and accuracy of knowledge on 10 items (sample item: “structured – unstructured”) and exhibited satisfactory reliability pre-instructionally (Cronbach’s $\alpha = .84$) as well as post-instructionally (Cronbach’s $\alpha = .85$). CAEB-variability measures beliefs about the stability and dynamics of knowledge on 7 items (sample item: “dynamic – static”) and exhibited satisfactory reliability pre-instructionally (Cronbach’s $\alpha = .74$) as well as post-instructionally (Cronbach’s $\alpha = .90$). The GCBS (General Certainty Beliefs Scale; Trautwein & Lüdke, in press) is a 7-item instrument that captures declarative beliefs about the certainty and attainability of scientific knowledge (sample item: “Scientific laws are universal truths.”). This scale also exhibited satisfactory reliability pre-instructionally (Cronbach’s $\alpha = .72$) as well as post-instructionally (Cronbach’s $\alpha = .83$).

Epistemological Sensitisation

Assumptions of the COPES-Model are related to more and less sophisticated epistemological beliefs (see above). To consider these claims experimentally it is necessary to manipulate epistemological beliefs systematically: Two versions of an introduction to “genetic fingerprinting” were administered to two matched sub-samples of students as an instructional intervention that we termed epistemological sensitisation. One sub-sample received an introduction which was neutral because it was purely factual. The other sub-sample received an epistemological instruction that was enriched with comments about the epistemological nature of selected facts (e.g., detailing scientific controversies) and thus should elicit more “sophisticated” evaluativistic epistemological beliefs.

The results show that the two sub-samples were adequately matched with regard to their epistemological beliefs (no significant pre-instructional differences could be detected: CAEB-texture: F (1,33) = 1.38, $p = .248$; CAEB-variability: F (1,33) = .01, $p = .937$; GCBS-certainty: F (1,33) < .01, $p = .965$). Additionally, consistent effects of the epistemological sensitisation could be detected in a repeated-measure analysis: A significant multivariate interaction (F (1,31) = 4.73, $p = .008$) was replicated univariately on the two CAEB scales (CAEB-texture: F (1,33) = 13.02, $p = .001$; CAEB-variability: F (1,33) = 7.95, $p = .008$). For GCBS-certainty, this interaction was not significant. Furthermore, significant univariate main effects for the repeated-measure factor emerged for the two CAEB scales (CAEB-texture: F (1,33) = 6.41, $p = .016$; CAEB-variability: F (1,33) = 6.81, $p = .014$). The main effects indicate that all students became more “sophisticated” after reading the introductions. The interactions demonstrate that students who read the epistemological introduction became significantly more “sophisticated” than the students who read the neutral introduction. The effects point in the same direction for GCBS-certainty but were not significant, potentially because this instrument captures more denotative aspects of epistemological beliefs that are not assumed to change easily.

For our research questions it is not important if this change is a fundamental and lasting modification of epistemological beliefs or a temporal effect on context-dependent epistemological resources (Hammer & Elby, 2003). We hereby acknowledge that our epistemological sensitisation might only have changed epistemological beliefs during the learning process (in situ). To conclude, the epistemological sensitisation can be considered a success and these experimental groups will be included as independent variable tapping epistemological beliefs in all subsequent analyses with regard to the impact of internal conditions.

Tasks of Different Complexity

Bloom’s revised taxonomy (Anderson et al., 2001) distinguishes between tasks affording cognitive processes of different complexity (in order of ascending complexity): (1) remember, (2) understand, (3) apply, (4) analyze, (5) evaluate, and (6) create. In this study only tasks from selected categories were used: Students first had to solve two tasks of the simplest Bloom-category remember (factual multiple-choice questions). These were followed by a very complex evaluate task (that required students to judge the adequacy of multiple DNA analysis methods for paternity testing), a quite simple understand task (which required an open answer) and another remember task. By this order of tasks it was possible to investigate if students enhanced their depth of processing if confronted with more complex tasks, but also if they were able to decrease their processing again if simple tasks required superficial strategies. The subsequent analyses will include task complexity as defined by these tasks as repeated-measure factor.

Additionally, students' answers to these tasks will be analysed as dependent variables tapping their learning outcome. For the simple remember tasks only correctness of answers will be determined. For the complex evaluate task on the other hand the open answers will not only be analyzed with regard to correctness of the final answer, but also with regard to multiple qualitative sub-scores (e.g., quality of argumentation, correctness of the evaluation of single DNA analysis methods, correctness of the final conclusion, and overall sum score made by adding up all sub-scores).

The Hypertext on Genetic Fingerprinting

Tasks were solved with a hierarchical hypertext on genetic fingerprinting that was implemented in MetaLinks (Murray, 2003). This hypertext encompasses 106 nodes that belong to three thematic hierarchically structured chapters (i.e., about mtDNA analysis, STR analysis, and Y-STR analysis) and appendices about further biological background, examples, and nodes about potential problems. During students' learning phase all concurrent navigational actions were automatically recorded. From these logfiles, two scores were computed that were used as repeated-measure dependent variables in all subsequent analyses. Time for task completion (TTC) contains the exact time a student needed to complete each single task. And the number of accessed nodes (NAN) explicates how many nodes a student accessed for each task.

Students' Concurrent Thoughts

Students' concurrent thoughts were captured by prompting them with the question "What are you currently thinking about?" in fixed time intervals (approximately every 2 minutes). Students' answers were coded as either indicating their planning (PL), their enactment (EN), or their reflection or revision (REV) processes. Two raters blindly coded the protocols of a sub-sample of 12 students (34 % of the total sample). For 73.4 % of the prompts (n = 259) the two raters assigned the same category. All differences were resolved by discussion. Subsequently, one of the two raters coded the remaining protocols. Thus, the numbers of these processes per task were used as repeated-measure dependent variable in all subsequent analyses.

Results

Because of the qualitative and explorative character of the study $p < .05$ was defined as significant and $p < .10$ as marginally significant. Because most students (i.e., n = 29, that corresponds to 82.8 % of the sample) finished all five tasks, statistical analyses will be performed across all five tasks. All students solved at least three tasks.

Do students adapt their learning process to task complexity?

This question was investigated with a methodology transferred from the calibration paradigm (Nelson & Dunlosky, 1991): First, it was determined if students learning processes significantly differed between tasks of different complexity by repeated-measure analyses (discrimination). Second, a systematic relationship between students' learning processes and task complexity was determined by computing within-subject Goodman-Kruskal Gamma correlations (G) between the dependent variables and the Bloom-Categories (n = 5, for the 5 tasks). These were subsequently Z-transformed into calibration indices.

A within-subject repeated-measure MANOVA across all five tasks was calculated for the variables capturing students' concurrent actions (TTC = time for task completion and NAN = number of accessed nodes) to determine discrimination. A significant multivariate main effect for the repeated-measure factor task was detected (F (8,20) = 10.20, $p < .001$) that was replicated univariately on both dependent variables (NAN: F (4,108) = 43.67, $p < .001$; TTC: F (4,108) = 32.11, $p < .001$). For both dependent variables the calibration graphs indicate a "peak" for the complex evaluate task. For example, students spent on average between 5 - 10 minutes on remember and understand tasks and they spent on average approximately 20 minutes on the evaluate task (TTC). This picture is corroborated by calibration indices of large effect size: For example, the mean calibration index for the number of accessed nodes (NAN) corresponds to a correlation of G = .90 and significantly differs from zero (t (34) = 6.55, $p < .001$). This positive association indicates that students accessed few nodes for simple tasks and accessed an ascending number of nodes with increasing task complexity. A similar picture was found for TTC (G = .94, t (34) = 8.04, $p < .001$).

A within-subject repeated-measure MANOVA across all five tasks was calculated for variables capturing students' concurrent thoughts (PL = planning, EN = enactment, and REV = reflection / revision) to determine discrimination. A significant multivariate main effect of the repeated-measure factor task was detected (F (12,23) = 27.55, $p < .001$) that was replicated univariately on all dependent variables (PL: F (4,136) = 24.47, $p < .001$; EN: F (4,136) = 30.46, $p < .001$; REV: F (4,136) = 25.53, $p < .001$). For all kinds of concurrent thoughts, the overall picture was similar: Students gave more answers for the complex evaluate task than for the simpler remember and understand tasks, indicated by a "peak" in the calibration graphs. This picture is corroborated by calibration indices of large effect size (PL: G = .88, t (34) = 4.83, $p < .001$; EN: G = .97, t (34) = 9.42, $p < .001$; REV: G = .93, t (34) = 5.91, $p < .001$).

Students' learning outcome is captured by their answers to the tasks. The number of written words was compared between the two open answer tasks to determine discrimination: Students wrote significantly more for the complex evaluate task (about 120 words) than for the simpler understand task (about 60 words; t (31) = 5.89, p < .001). Task difficulty (the percentage of correct answers in this sample) was compared between all five tasks in a repeated-measure ANOVA. All tasks were solved correctly by more than 60 % of the students. No significant differences of the repeated-measure factor task could be detected (F (4,25) = 1.92, p = .138). Because of the lack of discrimination for task difficulty no calibration indices were computed for this variable.

Are these adaptation processes impacted by epistemological beliefs and prior domain knowledge?

In order to answer this question the quasi-experimental prior domain knowledge groups (biology students versus humanities students) as well as the experimental groups of the epistemological sensitisation (epistemological introduction versus neutral introduction) were included as dichotomous factors in the repeated-measure discrimination analyses. And the calibration indices were compared between groups.

Prior Domain Knowledge

The MANOVA for students' concurrent actions (NAN = number of accessed nodes and TTC = time for task completion) revealed a marginally significant multivariate main effect (F (2,23) = 3.23, p = .052) and marginally significant interaction with the repeated-measure factor task (F (8,17) = 2.43, p = .059). Univariately these effects were only significant for TTC (main effect: F (1,24) = 6.83, p = .015; interaction: F (4,96) = 2.52, p = .046). The corresponding calibration graph indicates that humanities students spent more time on all tasks (main effect) but one (interaction): For the last remember task, humanities students were faster.

The MANOVA for students' concurrent thoughts (PL = planning, EN = enactment, and REV = reflection / revision) revealed a significant multivariate main effect (F (3,30) = 4.64, p = .009) and a significant multivariate interaction with the repeated-measure factor task (F (12,21) = 2.61, p = .026). Univariately these effects were only significant for PL (main effect: F (1,32) = 9.90, p = .004; interaction: F (4,128) = 3.16, p = .016). The corresponding calibration graph indicates that humanities students engaged more frequently in planning processes across all tasks (main effect) and that this effect was especially pronounced for the complex evaluate task (interaction).

The ANOVA for the learning outcome (task difficulty) revealed a significant interaction with the repeated-measure factor task (F (4,23) = 3.32, p = .028): The corresponding calibration graph indicates that humanities students in general were less successful at solving tasks correctly, but solved the second remember task better than the biology students did. To get an even more detailed insight, an additional MANOVA was calculated for all sub-scores for the complex evaluate task. Results indicate two effects: A significant effect for giving correct evaluations (F (1,25) = 4.52, p = .044) and a marginally significant effect for the overall sum score (F (1,25) = 3.01, p = .095). In both cases, biology students outperformed humanities students.

Additionally, one effect on students' calibration was detected: Humanities students tended to calibrate their number of accessed nodes (NAN) stronger to task complexity than biology students (F (1,31) = 3.82, p = .060; biology students: G = .74, humanities students: G = .95). This indicates, that humanities students accessed more nodes for the understand task than for the remember tasks and more nodes for the evaluate task than for the understand task. For biology students this rank order was not as pronounced.

Epistemological Sensitisation

The MANOVA for students' concurrent actions (NAN = number of accessed nodes and TTC = time for task completion) revealed a significant univariate interaction for TTC (F (4,96) = 3.41, p = .012). The corresponding calibration graph (Figure 1, left) indicates that students who read the epistemological introduction spent less time on simple remember tasks, but significantly more time on the complex evaluate task than their counterparts who read the neutral introduction.

The MANOVA for students' concurrent thoughts (PL = planning, EN = enactment, and REV = reflection / revision) revealed a marginally significant multivariate main effect (F (3,30) = 2.72, p = .062), but a univariately significant main effect and a univariately significant interaction for PL (main effect: F (1,32) = 7.62, p = .009; interaction: F (4,128) = 3.61, p = .008). The corresponding calibration graph (Figure 1, right) indicates that students who read the epistemological introduction more often engaged in "planning" processes across all tasks (main effect), and that this effect was especially pronounced for the complex evaluate task, still detectable for the understand task, but almost invisible for the remember tasks (interaction).

T-test for the learning outcome (number of written words) revealed a marginally significant main effect (F (1,28) = 3.29, p = .081): Students who read the epistemological introduction wrote significantly more words in both tasks with open answers. The ANOVA for task difficulty revealed a significant main effect (F (1,26) = 4.53, p = .043). The corresponding calibration graph indicates that students who received the epistemological introduction performed worse across all tasks than the students who received a neutral introduction. To get an even more detailed insight, an additional MANOVA was calculated for all sub-scores for the complex evaluate task (see above). Results indicate effects for quality of argumentation (F (1,25) = 7.19, p = .013) and for correctness of the final conclusion (F (1,25) = 7.60, p = .011). While students with the epistemological introduction outperformed students with the neutral introduction on the quality of argumentation, the picture was reversed for correctness of the final conclusion.

Additionally, one effect on students' calibration was detected: Students who received the epistemological introduction tended to calibrate their time for task completion (TTC) stronger to task complexity than students who received the neutral introduction (F (1,31) = 3.02, p = .092; neutral introduction: G = .88, epistemological introduction: G = .97). This indicates that the epistemological introduction led to a rank order of tasks with regard to processing time analogous to the Bloom-Categories (i.e., remember < understand < evaluate) while this was not as strongly the case for the neutral introduction.

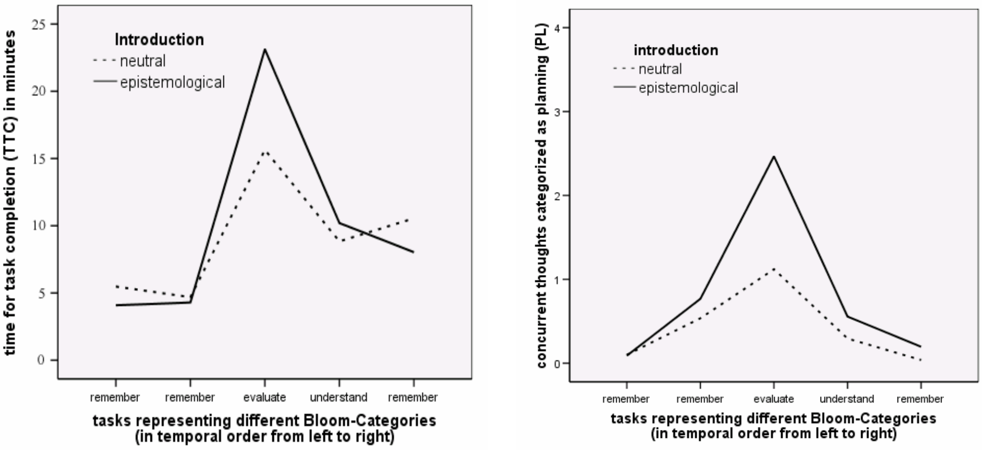

Figure 1. This Figure visualizes the effects of the epistemological sensitisation for time for task completion (TTC; left) and for planning (PL, right).

Does Adaptation Impact the Learning Outcome?

An overall learning outcome score was computed by summing up the number of correctly solved tasks (i.e., thus this score ranged from 0 to 5 points). On average, students scored 4.03 points (SD = .82) which corresponds to 81 %. The impact of internal condition (i.e., students' prior domain knowledge and their epistemological beliefs) was already extensively investigated in the previous analyses. But the predictive power of further learning process variables was tested: First, variables capturing students' concurrent learning process that were interpreted as dependent variables before were used as predictors and were correlated with this score: the overall number of accessed nodes (NAN), the overall time for task completion (TTC), the overall number of concurrent thoughts categorized as "planning" (PL), "enactment" (EN) and "reflection / revision" (REV). Second, the calibration indices for these five variables were also used as predictors. Results indicate only one significant correlation: The calibration indices for the time for task completion (TTC) were negatively correlated with the overall learning outcome score (r = -.52, p = .004, n = 29). Students who better adapted their time for task completion to the complexity of the learning tasks solved fewer tasks correctly.

Discussion

With regard to students' adaptation to task complexity, students demonstrated their ability sufficiently: Repeated-measure (M)ANOVAs across all tasks consistently indicate significant discrimination and calibration indices of large effect size consistently indicate significant calibration. The logfiles capturing students' concurrent actions reveal that students spent significantly more time and accessed more nodes for more complex tasks. Students' concurrent thoughts point in the same direction: They show an increase in all processes for more complex tasks. This finding may seem trivial at first glance because more time spent on a task automatically leads to more prompts per task which elicit more concurrent thoughts. Nonetheless students' could have only increased their superficial enactment without increasing their metacognitive involvement like planning (cf. Stahl, Bromme, Stadtler, & Jaron, 2006). Thus, these results show that students increase their concurrent cognitive as well as their concurrent metacognitive processing for more complex tasks. Additionally, this adaptation is also visible in students' answers (learning outcome): They write more for complex tasks. The fact that almost all tasks were solved equally well (lack of discrimination effect for task difficulty) on the other hand supports the success of students' adaptations: The superficial processing of simple tasks and the elaborate processing of more complex tasks both led to almost equal success.

With regard to prior domain knowledge, the effects are mostly consistent: Results indicate that biology students were faster (also cf. Lawless, Brown, Mills, & Mayall, 2003) and needed to employ less overt planning during the task solution process (also cf. Winne & Hadwin, 1998), but still outperformed the humanities students (also cf. Ford & Chen, 2003). Consistently, calibration results indicate that biology students did not calibrate their number of accessed nodes during their self-regulated learning process as strongly to task complexity as the humanities students (also cf. Glenberg & Epstein, 1987). Most likely, humanities students needed more time because they did not understand all technical terms and they might have needed to access more nodes and engage in more metacognitions to compensate for their lack of knowledge. Because especially the complex task afforded reading multiple nodes, this might have resulted in a higher calibration for humanities students. However, despite humanities students' apparently deeper processing their strategy was not enough to compensate for biology students' initial advantage (cf. learning outcome).

With regard to epistemological beliefs, the epistemological sensitisation also elicited consistent effects: Students who read the epistemological introduction were faster on simpler tasks but spent more time on complex tasks. Consistently, calibration results indicate that students with the epistemological introduction calibrated their time for task completion during their self-regulated learning process stronger to task complexity than students with the neutral introduction. Furthermore, students who read the epistemological introduction employed more metacognitive planning during the task solution process (Bendixen & Hartley, 2003; Kardash & Howell, 2000), especially for the complex evaluate task. Therefore, this intervention seemed to have triggered more flexible epistemologies and learning strategies (Elby & Hammer, 2002). With regard to the learning outcome, reading the epistemological introduction was associated with more written words and superior argumentation (Mason & Boscolo, 2004), but seemed to be detrimental for overall success in terms of correctness. Most likely, the epistemological introduction triggered an awareness of the complexity, uncertainty, and variability of knowledge. This awareness might have elicited standards of deeper learning and thus a more elaborate self-regulated learning process including better adaptation to task complexity. Additionally, students might have tried to convey their new insights by writing adequately complex answers. However, this increased awareness might also have made it more difficult for students to finally decide on one single correct answer: Some comments in the epistemological introduction stressed the multiplicity of possible opinions and the difficulty to find final truths.

With regard to the learning outcome, results are counterintuitive: The COPES-model (Winne & Hadwin, 1998) clearly predicted that better adaptation to external conditions (here: calibration to task complexity) should also be beneficial for the learning outcome while the reverse effect was detected in this study. One viable explanation concerns the task specificity of this effect. If learning outcome is not operationalised as correctness of answers but instead by measures also considering the quality of students' answers, this effect disappears.

These results demonstrate that students not only adapt their learning to task complexity in the planning stages of learning (i.e., task definition, goal setting and planning according to the COPES-model) and that epistemological beliefs do not only impact these planning processes, but that similar effects can be detected in subsequent stages of learning where students' actively have to solve tasks of different complexity (i.e., enactment and adaptation according to the COPES-model). Additionally, these results demonstrate that the theoretically assumed causality between epistemological beliefs and learning processes can also be detected empirically: "Sophisticated" beliefs cause more elaborate learning processes and not vice versa. Therefore, implementing explicit discourse about epistemological questions in a learning setting (like the epistemological sensitisation) might be an adequate instructional intervention to scaffold adequate learning.

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