Effects of Task Difficulty and Epistemological Beliefs on Metacognitive Calibration: A Pilot-Study

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Abstract: This article presents a pilot study, which is part of a comprehensive project to examine the impact of epistemological beliefs on metacognitive calibration during learning processes within a complex hypermedia information system. More specifically, this pilot study investigates (1) if learners differentiate between tasks of different complexity, set goals and plan accordingly and (2) whether such adaptive learning behavior is influenced by their epistemological beliefs. Students (n = 72) inspected a set of six learning tasks and answered multiple questions derived from the COPES-model of self-regulated learning (Winne & Hadwin, 1998), e.g. they judged the importance of specific learning strategies for a particular learning task. Furthermore, they filled in inventories measuring their epistemological beliefs. Results confirmed significant influences of task complexity and epistemological beliefs on students' judgments.

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 these fields of research is that learners' epistemological beliefs develop from more "naive" views (e.g., knowledge is absolute; knowledge is an accumulation of facts) to more "sophisticated" beliefs (e.g., knowledge is relative and contextual, knowledge is a complex network) during educational processes. An increasing number of empirical studies show that more sophisticated epistemological beliefs are related to more adequate learning strategies and better learning outcomes. To give some examples from traditional classrooms: college students' epistemological beliefs influence their processing of information and their monitoring of comprehension (e.g., Schommer, 1990), their academic performance (e.g., Schommer, 1993), conceptual change (e.g., Mason & Boscolo, 2004), cognitive processes during learning (e.g., Kardash & Howell, 2000), and their engagement in learning (e.g. Hofer & Pintrich, 1997). 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 a good predictor of learning outcomes in learning with hypertexts. Concerning learning with other new media, Windschitl and Andre (1998) found that students with more sophisticated beliefs learned more with constructivist simulations than students with less sophisticated epistemological beliefs. 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 affect students' information retrieval from the Internet (e.g. Hofer, 2004). Nonetheless the exact functional relationship between epistemological beliefs and learning, i.e. how they exactly exert their influence, still remains an open issue. Most recent views on epistemological beliefs and learning agree that such beliefs are somehow part of metacognition (e.g. Hofer, 2004; Kitchener, 1983; Kuhn, 2000), but empirical evidence to confirm these assumptions is weak.

COPES-Model of Self-Regulated Learning

An encouraging theoretical background that helps to specify such a functional relationship is given by the COPES-model (e.g. Winne & Hadwin, 1998, see figure 1 for a visualization) that incorporates epistemological beliefs as an important condition for the whole learning process. 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, and what constraints and resources are in place. An important product of this stage is the student's perception of the goal of the task. Based on this personal 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 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). In the center of this architecture are processes of metacognitive monitoring and controlling that students' might use to calibrate their learning process to perceived demands of the learning task. If and how such metacognitive calibrations might occur depends on the five constituents of the cognitive architecture: *Conditions* pertain to external task conditions (e.g. time, resources) as well as to internal cognitive (e.g. prior knowledge, motivation) conditions. Epistemological beliefs are a part of these learner-related internal conditions. 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 essay or an observable behavior). 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 (e.g. targeted time on task, level of understanding and information sources). *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.

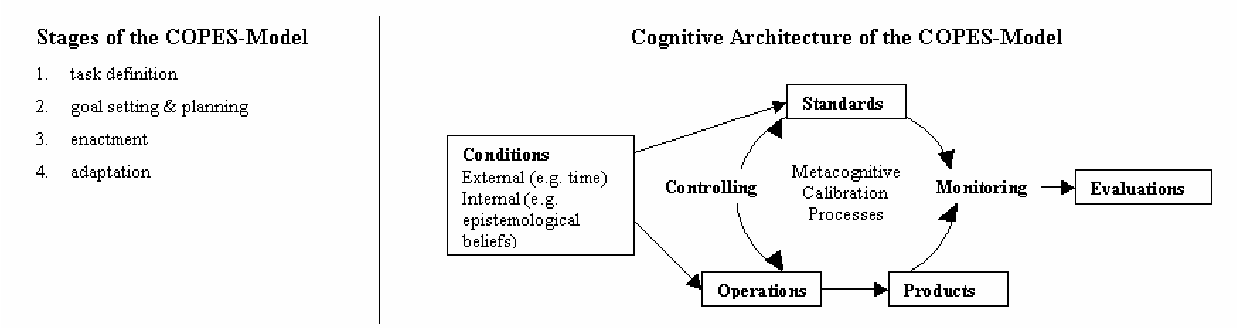

Figure 1: Visualization of the COPES-model

Task Difficulty, Epistemological Beliefs, and Metacognitive Calibration: A Pilot-Study

Based on the COPES-model we hypothesize that epistemological beliefs influence all stages of self-regulated learning within a hypermedia learning system. More specifically, we assume that metacognitive calibration processes are affected strongest, e.g. the calibration or adaptation to task complexity. To illustrate this functional relationship between epistemological beliefs and self-regulated learning, imagine a learner in the stage of goal setting and planning with a more naive belief that knowledge is simple and stable. As epistemological beliefs directly influence the standards, the learner might probably set quite superficial goals (e.g. "The goal is archived if I have learned the important facts."; "I can complete this task in a short time.") compared to a more sophisticated learner who believes that knowledge is complex and relative. The epistemological beliefs also directly influence the operations, thus a more naive learner might probably also plan (and later on use) rather superficial operations for task completion (e.g. memorizing) compared to a more sophisticated learner who might plan strategies of deeper elaboration. These differences might become even more pronounced in subsequent learning stages and with regard to more complex tasks. Consequently, we hypothesize, that learners with more sophisticated beliefs should be better in calibrating to task complexity. Within a larger project (Bromme & Stahl, 2004) we will test this general hypothesis about epistemological beliefs as important predictor for calibration with regard to each stage of self-regulated learning according to the COPES-model. Three main experiments are planned: one experiment will mainly deal with the stages of task definition and of goal setting and planning, whereas the other two experiments will investigate the real learning process, including enactment and adaptation. All experiments will have common elements: students work with a hypermedia information system on genetics, especially about the topic "genetic fingerprinting". They have to complete learning tasks with different levels of complexity, which have been established based on Bloom's revised taxonomy (Anderson et al., 2001). In this article we present the results of a pilot study. Although one objective of this study was to develop and evaluate material, e.g. appropriate learning tasks and a questionnaire measuring task definition, goal setting and planning, this pilot study also explored the following research questions: (1) Do learners differentiate between tasks of different complexity according to Bloom's revised taxonomy and do they plan their goals and strategies accordingly (i.e. do they calibrate to task complexity)? (2) Is this calibration process influenced by epistemological beliefs? To investigate these issues we operationalized calibration in the following way: We presented the participants with learning tasks that differed in complexity according to Bloom's revised taxonomy. Good calibration was diagnosed when participants' subjective judgments to items concerning task definition, goal setting and planning (e.g. judgment of importance of the strategy "elaborating") showed a significant relationship with the objective taxonomy (e.g. ascending judged importance of "elaborating" with ascending task complexity).

Method

Participants

Seventy-two students of biology (35 males and 37 females) took part in this study. The mean age was 22.5 years (SD = 1.6). Selected recruiting ensured adequate prior knowledge in molecular biology and adequate learning experience. On average the participants studied in the 4.9th semester biology or related majors (SD = 1.8) and already attended 8.8 (SD = 2.5) of twelve possible courses in molecular biology. The level of ability was confirmed by the results of a short knowledge test (8 points maximum; M = 7.4, SD = 0.9).

Materials

Epistemological Beliefs Questionnaires

Epistemological beliefs were measured by one domain-general instrument, the EBI (Epistemological Beliefs Instrument, Jacobson & Jehng, 1999), that measured students' general beliefs about the nature of knowledge and knowing, and with two domain-dependent instruments, the CAEB (Connotative Aspects of Epistemological Beliefs; Stahl & Bromme, submitted) and the DEBQ (Domain-specific aspects of Epistemological Beliefs Questionnaire, Hofer, 2000). Concerning these two instruments students' were asked to complete the items referring to the domain of genetics. Although it was not possible to replicate the original factor structures in all cases, meaningful solutions were obtained: The factor solution for the EBI encompassed the two original factors "certainty" (7 items, Cronbach's α = .76) and "simplicity" (7 items, Cronbach's α = .69) which explained 42 % variance. The solution for the CAEB comprised the original two factors "texture" (10 items, Cronbach's α = .82) and "variability" (7 items, Cronbach's α = .64) and explained 38 % variance. The solution for the DEBQ explained 36 % variance but differed from the original factors. It consists of two new factors, which we labeled as "definitude" (9 items, Cronbach's α = .74, e.g. "If scholars try hard enough, they can find the answers to almost anything.") and "accessibility" (6 items, Cronbach's α = .58, e.g. "I am more likely to accept the ideas of someone with firsthand experience than the ideas of researchers in this field.").

Learning Tasks

We developed learning tasks for the topic of genetic fingerprinting that varied in complexity according to Bloom's revised taxonomy (Anderson et al., 2001). All six *Types of Learning Tasks* (or "TLT-categories") of this hierarchical taxonomy were covered (i.e. in ascending complexity: remember, understand, apply, analyze, evaluate, and create). The construction and selection followed a cyclic process: first, textbooks and articles on the topic of genetic fingerprinting were examined. Second, two experts were introduced to the revised taxonomy and both constructed independently several exercises for all TLT-categories. As a result, a pool of 100 learning tasks was established. Third, the two content experts as well as three content novices, all deeply familiar with the revised taxonomy, categorized all learning tasks according to the TLT-categories in a blind trial. Divergence in the categorization was discussed by the raters and led to rephrasing or deletion of tasks. As a result a pool of 86 learning tasks was selected. For the final selection, only six tasks in each TLT-category were chosen, resulting in a total of 36 learning tasks, i.e. six versions per TLT-category. One example of the lowest TLT-category "remember" is a purely factual multiple-choice question, such as: "DNA is split by which procedure?. The most complex TLT-category of "create" on the other hand demands new creations such as predictions (e.g. "What would happen if law would allow the analysis of coding DNA in forensic medicine? Outline the most important consequences.").

COPES-Questionnaire

We developed a questionnaire to examine students' assessments of the first two stages of self-regulated learning, (1) task definition and (2) goal setting and planning. It was named COPES-Questionnaire after the model it was derived from (Winne & Hadwin, 1998). The construction of the questionnaire followed a cyclic process as well: a pool of 124 potential items was directly deduced from the COPES-model and from articles about metacognition and learning strategies (e.g. Garavalia & Gredler, 2003; Hadwin, Winne, Stockley, Nesbit & Woszcyna, 2001; Luyten, Lowyck & Tuerlinckx, 2001; Wild & Schiefele, 1994). Five experts successively edited this item pool. The resulting prototype of the COPES-questionnaire consists of 46 items. Most of these items have to be rated on a 7-point scale. According to the cognitive constituents of the COPES-model they cover students' assessments on *conditions* (headed by the question: "How important are the following conditions for the solution of the present task?", students have to rate 10 external / internal conditions like interest or prior knowledge), *operations* ("How important are the following learning strategies for the solution of the present task?", students have to rate 12 strategies like elaborating or memorizing), *evaluations* ("Rate your agreement to the following items.", students have to rate 6 statements like "this task is very complex" or "this task is easy to solve") and *standards* ("How important are the following kinds of information / information-sources for the solution of the present task?", students have to rate 18 items like newspapers, textbooks, facts and details, rules and procedures).

Procedure

All participants were recruited during regular university-courses in biology and received 12 € for participation. They worked in group-sessions with a maximum of 12 students. During the session each participant completed two questionnaires. The first questionnaire encompassed demographic questions, the three epistemological beliefs inventories and a short knowledge test. The second questionnaire consisted of six learning tasks each of which had to be evaluated with the COPES-questionnaire. Students were asked to imagine that they would have to solve the tasks with help of a hypermedia-learning environment about genetic fingerprinting while completing the questionnaire. To balance the six tasks per TLT-category, twelve different versions of this questionnaire were produced. Consequently, twelve participants judged each learning task. Each student evaluated learning tasks from all six TLT-categories presented in random order in a blind trial.

Results

Do learners differentiate between tasks of different complexity according to Bloom's revised taxonomy and do they plan their goals and strategies accordingly?

We decided to use multiple criteria to examine the first question. At first, ANOVAS for repeated measurements were calculated for each item. They compared judgments, e.g. about the importance of "elaborating", across all TLT-categories (*Types of Learning Tasks*) of ascending task complexity according to Bloom's revised taxonomy. We decided to define $\alpha < .05$ as significant because of the explorative nature of this study and found significant differences with regard to all 46 items. This is a first indicator that students differentiated between tasks of different complexity. As an example the results for the 12 items used to measure students assessments on operations are displayed in table 1 ("ANOVA results"). Second, to scrutinize the relationship two independent raters visually inspected the corresponding diagrams of means (see figure 2) across the six TLT-categories. Interrater reliability was 89 %. Both raters consistently classified 41 items.

(A) ascending trend **(B) specific trend for "apply"** **(C) no apparent trend**

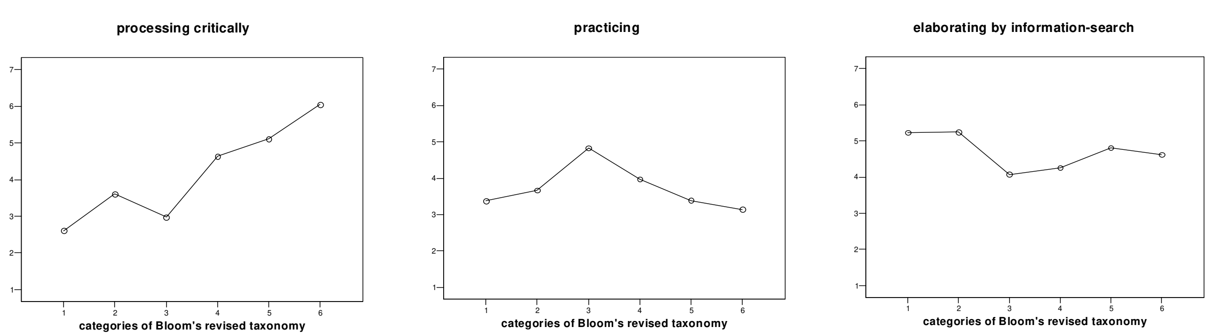

Figure 2: Examples of (A) a mostly ascending trend, (B) a specific trend for the TLT-category "apply" and (C) no apparent trend.

From these 26 items were classified as having a clear ascending or descending trend, i.e. a significant relationship or covariance with the taxonomy (even if the trend was not always strictly ascending / descending for all categories, see "processing critically" in figure 2A for an example). Further two items were classified as having a specific trend. For example, "practicing" had a peak for the third TLT-category "apply" (see figure 2B). 13 items had no clear trend, e.g. were seen as roughly equally important for all TLT-categories (e.g. "elaborating by information-search", see figure 2C). Third, correlations between the objective task complexity according to Bloom's revised taxonomy and students' subjective judgments concerning one item across all categories were computed (see table 1, "correlation with taxonomy"). 34 item exhibited significant correlations. With regard to a practical relevance of these correlations only correlation with a medium effect size (≈ .30) were seen as clear trends. This applied to 18 items. An overall comparison revealed that these 18 items showed clear ascending or descending trends over all three criteria (see table 1, "final classification"). The remaining items showed a specific trend (3 items) or other meaningful patterns (mostly that an item was seen as equally relevant for all TLT-categories). The first question can therefore be answered affirmative. Students acknowledge task difficulty according to Bloom's revised taxonomy and plan their goals and strategies accordingly.

Table 1: Sample results concerning the first research question for the items pertaining to "operations".

Items	**ANOVA results**	**expert rating**	**correlation with taxonomy**	**final classification**
Linking with prior knowledge	F (5,67) = 4.64**	no trend	.11*	no trend
Structuring	F (5,67) = 14.20***	trend	.34**+	trend
Integrating	F (5,67) = 25.98***	trend	.37**+	trend
Memorizing	F (5,67) = 14.83***	trend	-.36**+	trend
Analyzing	F (5,66) = 12.85***	disagree	.24**	no trend
Processing critically	F (5,66) = 40.73***	trend	.56**+	trend
Selecting	F (5,64) = 4.15**	trend	.19**	no trend
Planning	F (5,67) = 10.87***	trend	.29**+	trend
Elaborating deeply	F (5,67) = 12.73***	trend	.32**+	trend
Elaborating by discussion	F (5,66) = 20.39***	trend	.33**+	trend
Elaborating by information-search	F (5,54) = 5.71***	no trend	-.10*	no trend
Practicing	F (5,67) = 9.03***	specific	-.07	specific

* p < .05; ** p < .01; *** p < .001, + r ≈ .30

Is this calibration process influenced by epistemological beliefs?

Because of the explorative character of the study we tested different methods to investigate the effects of epistemological beliefs on calibration processes. We defined $\alpha < .05$ as significant and $\alpha < .10$ as a trend. All methods yielded significant results or trends for at least half the analyzed variables. In this paper we will present results of one of these methods as an example. We calculated calibration indices by computing the Z-transformed correlations between Bloom's objective revised taxonomy and students' answers to one item across all TLT-categories. Therefore, a strong positive calibration indicates a disagreement to a single item, e.g. importance of "elaborating", on easier tasks and an ascending agreement on more complex ones. A negative calibration on the other hand designates a reverse relationship: as tasks become more complex, the participants' agreement decreases. A calibration index of zero characterizes a nonexistent linear relationship between the participants' evaluations and objective task complexity. To explore the relationship between the epistemological belief dimensions and these calibration indices correlations were computed. We found significant effects or trends for 14 of the 18 items (with a total of 24 effects). We describe exemplary results for the items with apparent trends pertaining to "operations": Five of the seven items showed significant correlations. We found a significant negative correlation ($r = -.25$, $p < .05$) between calibration of "structuring" and "simplicity" (from the EBI). Therefore, students displayed better calibration when they believed in complex knowledge in general: the learning strategy structuring (e.g. producing outlines, concepts maps, or tables) was judged to be more important in more complex tasks. With regard to the learning strategy of "integrating" (e.g. writing an integrated outline from multiple sources) the correlations showed superior calibration for students with the beliefs in unstructured and vague (dimension "texture" from CAEB, $r = .27$, $p < .05$) and more ambiguous knowledge in genetics (dimension "definitude" from DEBQ, $r = -.33$, $p < .01$). The learning strategy "memorizing / learning by rote" displayed a positive trend between "variability" (CAEB) and calibration ($r = .21$, $p = .08$). Thus, the more students believed that knowledge in genetics is certain and unchanging the higher were their calibration indices. This result may seem counterintuitive at first, but a scatter-plot revealed that students who believed that knowledge in genetics is relative and flexible had higher but negative absolute values of calibration, and therefore judged the strategy of memorizing as less important with more complex tasks. Students who believed that knowledge is ambiguous ("definitude" from DEBQ) judged the learning strategy of "critical processing" (e.g. drawing independent conclusions) as more important in complex tasks than in easy ones and thus calibrate their judgments better to task complexity ($r = -.21$, $p = .08$). The more students' believed knowledge in general to be complex ("simplicity" from EBI, $r = -.29$, $p <. 05$) and knowledge in genetics to be ambiguous ("definitude" from DEBQ, $r = -.31$, $p < .01$) the better was their calibration for the strategy of "planning" (e.g. trying to get an overview, planning strategies of time): planning was seen as increasingly important with more complex learning tasks. It can be summarized that the second question should be answered affirmative: the calibration process is significantly influenced by epistemological beliefs.

Discussion

This article presents a pilot study that is part of a research project to examine the effects of epistemological beliefs on metacognitive calibrations during learning processes within a complex hypermedia system. Starting from the COPES-model (Winne & Hadwin, 1998) we plan to examine the effects of students' epistemological beliefs on all stages of a learning process in detail. The main goal of the pilot study was to develop the experimental material for the main studies. Nevertheless the pilot study also gave first insights in students' metacognitive calibrations. We explored the first two stages of the COPES-model: the stages of individual task definition and of goal setting and planning. The first aim of this research was to examine if students differentiated between tasks of different complexity according to Bloom's revised taxonomy and if they set their goals and plans accordingly. We used a new questionnaire to examine this question and asked students to judge conditions, operations, evaluations and standards for tasks with different complexity. Depending on the criteria, between 18 and 34 of the 46 items showed clear ascending or descending trends, i.e. covariance with objective task complexity. The first research question could be answered affirmative: the results clearly show that students do monitor task complexity and calibrate their goal setting and planning accordingly. Furthermore, even the results without an apparent trend are meaningful, e.g. students judged motivation and interest equally important for all learning tasks. Nevertheless, these results should be seen as preliminary because the development and selection of experimental material that led to "noise" and variance in the data, e.g. testing six different versions of learning tasks per category. Against this background, it seems even more promising that consistent effects were found; probably the real effects were even underestimated. The second aim of this research was to examine if these calibration processes were affected by students' epistemological beliefs. We found clear effects even with this exploratory design, i.e. the reported calibration indices revealed consistent and meaningful results. In general, students with more relativistic epistemological beliefs were better able to monitor task difficulty and to better calibrate their goal setting and planning accordingly. Therefore, the second question could be answered affirmative as well. Nonetheless, these results are highly explorative for two reasons: first, we tested different questionnaires to measure epistemological beliefs (because of the development of material). A main problem in research on epistemological beliefs is that it is often not possible to fully replicate the original factor structures of the instruments. We found meaningful factor solutions for the CAEB and the EBI that were nearly similar to previously found solutions. Only the dimensions used for the DEBQ were different from original ones and therefore we decided to rename them. The second reason concerns the purely correlative nature of the investigated relationship between epistemological beliefs and calibration to task complexity. Because of this fact, no directionality of this influence could be convincingly diagnosed. Instead of epistemological beliefs influencing calibration to task complexity it could also be assumed that differential exposure to and experience with (molecular) genetics and different tasks evoked the formation and reinforcement of specific epistemological beliefs (i.e. "I had to memorize lot of facts about DNA in molecular genetics. Therefore, the knowledge in genetics has to be very certain."). In summary, there is a relationship between epistemological beliefs, monitoring task complexity and goal setting and planning. But so far the exact nature of this relationship remains pending. Further, more experimental studies with more valid epistemological beliefs inventories are needed. From these results it can be concluded that students use processes of metacognitive calibration in the planning stages even before they actually start learning (with a hypermedia system). It can be assumed that subsequent learning processes are influenced. Therefore, epistemological beliefs as well as formulation of learning tasks (and corresponding task complexity) exert a strong influence in earlier learning stages. Consequently, early stages of the learning process might be considered more seriously for the design of (hypermedia) learning-scenarios. We can conclude that this theory driven pilot study clearly showed that the COPES-model is a suiting framework for investigating the relationship between epistemological beliefs, task complexity, metacognitive monitoring and calibration of goal setting and planning. All results are very promising on the one hand but clearly only explorative in nature so far on the other hand. Further experiments will investigate the research questions more deeply.

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