Interactions of Expertise and Prior-Knowledge Activation with Low-Coherent and High-Coherent Concept Mapping Tasks

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Abstract

The following experiment investigated effects of low- and high-coherent prior-knowledge activation using concept maps. Thereby, we refer to and extend coherence-effects from text comprehension (McNamara & Kintsch, 1996) to prior-knowledge activation. Low-coherent prior-knowledge activation was operationalized by conditions of creating-and-labeling-lines between provided concepts, high-coherent prior-knowledge activation by labeling provided lines in a concept mapping task. Subjects with two different levels of expertise (43 high-school and 45 physics university students) were randomly assigned to three conditions (1) no prior-knowledge activation (2) creating-and-labeling-lines and (3) labeling-provided-lines. Results confirm a positive effect of prior-knowledge activation, a positive effect of expertise, and an interaction between expertise and the coherence of prior-knowledge activation in the posttest.

Keywords: Prior-knowledge activation; concept mapping; coherence.

Introduction

Prior-knowledge is one of the most important prerequisites for learning (e.g., Ausubel, 1968). It influences learning through cognitive processes of selection, organization, integration, and recall (Mayer, 1997; Renkl, 1996). (1) For selection, prior-knowledge focuses the learner's attention on relevant information and away from distractions, thus saving information-processing resources. (2) For organization, prior-knowledge facilitates the combining of information into meaningful ‘chunks’ that can be processed as a whole, again saving information-processing resources. (3) For integration, prior-knowledge provides a framework or scheme through which new information can be actively assimilated (integration in existing schemes) or accommodated (modification of existing schemes that conflict with the new information). (4) For recall, the influences of prior-knowledge on the selection, organization, and integration of new information reduces the amount of information chunks to be recalled and provides association cues for accessing information from long-term memory.

Ausubel (1968) emphasized the importance of prior-knowledge and developed the idea of the advance organizer. He did not, however, provide educators with simple functional tools to assess and activate prior-knowledge (Novak & Gowin, 1984). Based on Ausubel's work, Novak and Gowin, 1984 described hierarchical concept maps as a tool for getting students to examine their prior-knowledge before studying new materials. Concept maps provide an external network-like representation of knowledge structures and consist of spatially grouped nodes with key-words representing concepts, connection lines representing the semantic connection of concepts, and labels on the lines to specify the kind of the semantic relation.

Concept maps may be created entirely by the student. Alternatively educators may prepare incomplete maps and leave specific activities, for example creating and labeling the connection lines, for the learners. Research has shown that different mapping tasks evoke different cognitive and metacognitive processes (Ruiz-Primo, Shavelson, Li, & Schultz, 2001). A think-aloud study from Gurlitt, Renkl, Motes, and Hauser (2006) has shown that the low-coherent mapping task of creating-and-labeling lines elicits more organization- and model-construction processes compared to the high-coherent mapping task of labeling provided lines. Think-aloud statements were labeled as organization processes if the relationship between two concepts was processed. Think-aloud statements were classified as model-construction processes if subjects drew a conclusion or related more than two concepts with each other. Model-construction processes focus on higher-order relations; they should be especially useful for the construction of higher-order structures (Gentner, 1983) in domains with interacting relations.

Although external representations as concept maps influence the internal mental models and learning, this influence is not a straight-forward process. Instead there may be complex interactions between the level of prior-knowledge and the task used for prior-knowledge activation. This possibility of different instructional methods for different levels of expertise is supported by research about learning from texts (McNamara, Kintsch, Songer, & Kintsch, 1996; McNamara & Kintsch, 1996) that shows an interaction between the level of prior-knowledge and text coherence: High-knowledge readers learned more after reading a low-coherence text, while low-knowledge readers benefited more from a high-coherence text. In these experiments, high coherence was operationalized by inserting linking words for better argument overlap, making important references explicit, and rearranging sentences in a way that learners first encountered already possessed information and then to be connected new information (see also Britton & Gulgoz, 1991).

In the following experiment we investigated how high- and low-coherent concept-mapping tasks may be used to activate prior-knowledge. In addition to the activation of specific concepts, learners should get involved in organization and model-construction processes (relationships between more than two concepts). Similar to research about learning from texts we investigated how two different levels of expertise interact with the coherence of prior-knowledge activation.

Research Questions

The first three questions relate to the effects of prior-knowledge activation on learning outcomes. The next two questions investigate effects of prior-knowledge activation on the navigation and goal-orientation in the hypertext used for the learning phase; in this context, goal-orientation refers to the extent to which learner goals instead of 'bottom-up' processes drive navigation. The last question examines possible differential effects on questions that learners voluntarily asked themselves after low- vs. high-coherent prior-knowledge activation and before hypertext reading.

1. Does prior-knowledge activation with concept maps improve results in the posttest?
2. Does a higher level of expertise improve results in the posttest?
3. Do participants with a higher level of expertise benefit from low-coherent prior-knowledge activation, while participants with a lower level of expertise benefit from high-coherent prior-knowledge activation?
4. Does prior-knowledge activation influence the number of pages visited in the hypertext?
5. Does prior-knowledge activation influence the perceived goal-orientation?
6. Does low- and high-coherent prior-knowledge activation have differential effects on self-questioning?

Method

Participants and Design

We used a 3x2 design with prior-knowledge activation (no map, create-and-label-the-lines map, label-the-lines map) and level of expertise (physics-major student at university, student at high school) as between-subjects factors. Forty-three German high-school students (mean age *M* = 17.6 years; 21 female, 22 male) and 45 German physics-major students (age *M* = 21.6 years, 14 female, 31 male) participated in the study. The experiment took about 1 hour and 20 minutes. The participants received 10 EUR (US$ 13) for participation. While all participants had previous lessons about the content 'motion on inclined plane', physics students had additional lessons about this topic at university level. Participants were randomly assigned to one of the following conditions:

1. The low-coherence group activated prior-knowledge by a creating-and-labeling-lines task, reflected about possible knowledge gaps, and studied a hypertext about motion on inclined plane.
2. The high-coherence group activated prior-knowledge by a labeling-provided-lines task, reflected about possible knowledge gaps, and studied a hypertext about motion on inclined plane.
3. The baseline group just studied a hypertext about motion on inclined plane.

The baseline group was included to estimate the effect of prior-knowledge activation with concept maps and reflection about one's own knowledge.

Procedure

First, participants in the prior knowledge activation groups received written instructions that explained concept mapping. The instructions included an example from biology. It explained how to label the lines ('+' for a positive relationship or '-' for negative relationships, or a '?' for indecisive for either one of the former two). Using the same example, participants also completed a label-provided-lines mapping task and a create-and-label-lines mapping task on the computer to familiarize themselves with the software used in this study. The mapping-software (Easy-Mapping Tool; http://www.cognitive-tools.com) was specifically adapted to the research so that concepts could not be changed, rearranged, or added. The only possible actions for participants were drawing and labeling lines. All participants were informed that there would be no 'calculation-questions' in the posttest.

In the high-coherent group, participants had to label provided connection-lines between physics concepts that were relevant to the topic "motion on inclined plane" (Figure 1).

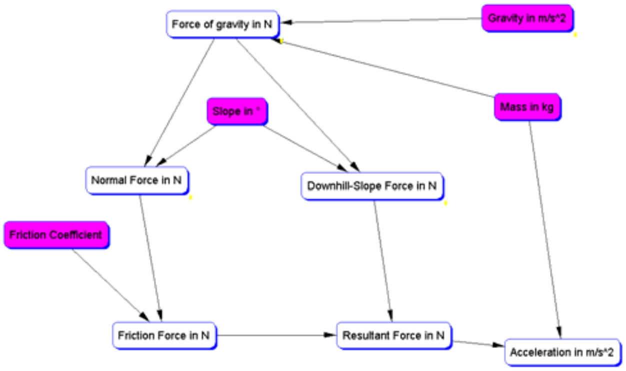

Figure 1: High-coherent prior-knowledge activation, labeling provided lines

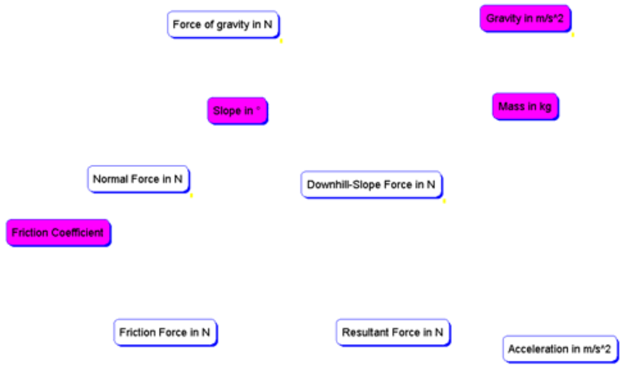

Figure 2: Low-coherent prior-knowledge activation, creating and labeling lines

In the low-coherent group, participants had to create and label connection-lines (Figure 2) between the same concepts.

Both groups were informed about the goal of the mapping-task - to find out for themselves what they already knew and did not know. After 6 minutes, learners in the prior knowledge activation groups had 4 minutes to reflect on their knowledge gaps and to formulate questions if they liked. The self-questioning task was introduced to bridge the gap between the two different representations, the mapping task and the following hypertext. Therefore, possible self-generated questions were also available in the hypertext. The hypertext and possible self-generated questions were presented on a split-screen: The left-side of the split-screen included the hypertext about motion on inclined plane, while the right side incorporated the voluntarily generated questions. Participants were not ‘forced’ to answer their previously generated questions. Learners of the baseline group only studied the hypertext for 20 minutes without prior-knowledge activation. A clock counting from 20 minutes until 1 minute was provided inside the learning-environment. One minute before the end of the learning phase, learners were reminded to come to an end, and after the last minute, learners were interrupted and asked to work on the posttest. The time for writing down answers to open questions was visualized and controlled by the computer, automatically reminding learners to come to an end 30 seconds before the provided time ended.

Dependent Variables

Measures included the rating of the questions asked after prior-knowledge activation, self-rated goal-orientation, the number of pages visited in the hypertext, the posttest score and the control variable ‘physics grades in the last two years in high-school’.

As we investigated prior-knowledge activation effects, we did not use a pretest (which would have been also a type of prior-knowledge activation) to split learners into high- and low-knowledge readers (McNamara et al., 1996; McNamara & Kintsch, 1996). Instead we used learners with different levels of expertise. In order to control for the variation of high-school knowledge about physics within groups we asked participants about their physics grades in the last two years of high school.

Two raters categorized the questions that participants asked themselves after prior-knowledge activation. The categories were related to the ones used the analyses of thinking-aloud during such mapping tasks (Gurlitt et al. 2006): (1) *Organization questions* were defined as questions asking if two concepts are related. (2) *Reflection questions* were defined as reflecting about the details of the relationships between two concepts. (3) *Model-construction questions* were defined as questions about the interrelations in cluster of variables. (4) *Definition questions* referred to the definitions of certain concepts. Interrater agreement for the single categories was acceptable to good (from r = .67 to r = .91).

As another learning process parameter, we recorded the number of pages visited. The parameter indicated whether the hypertext was explored in a focused or more explorative way. Learners were also asked to rate on a 6-point rating scale whether they used a goal-oriented approach or whether they were rather driven by the links (1 equals 'I've been driven by the links all the time'; 6 equals 'I have searched for specific information all the time').

A posttest assessing the learning outcomes evaluated the understanding of the learning contents and not computational skills in this content sub-domain. It included three open format questions and six multiple choice items. Newtonian mechanics applied to the motion on inclined plane includes relations between mass, gravity, slope, inertia, friction, and forces. These relations may only be fully understood considering their complex interplay. Therefore the following open questions focus on the understanding of relationships between concepts: The first open question asked participants to explain during five minutes the relationship between mass and acceleration. The second and third open question asked participants to write about the effects of gravity increase (three minutes) and of friction increase (three minutes). We also asked six questions on relationships in a multiple choice format, for example, the greater gravity the … acceleration. Students had to decide between 'the more', 'the less', 'equal', 'not enough information to decide' and 'I don't know'. The latter was used to improve the chance for honest answers and reduce the occurrence of guessing.

Multiple choice questions were scored correct or incorrect. All open questions were rated by scores between 0 and 5, depending on the inclusion of the interplay between mass, gravity, slope, inertia, friction, and forces. Raters judged the quality of the answers by considering whether answers showed simple recall or a deeper understanding of relations and especially relations between relations. The maximum score (five) was assigned for a logical and clear argumentation chain considering relations and relations between relations. The minimum score (one) was assigned if the answer did not show an understanding of any relation between concepts. All written answers to the open questions were scored independently by two raters. Interrater agreement was high (from $r = .79$ to $r = .88$). As all of these posttest items measured conceptual understanding, they were aggregated to an overall score of learning outcomes.

Results

An alpha level of .05 was used for all statistical tests. As an effect size measure, we used partial η^2, qualifying values <.06 as small effects, values in the range between .06 and .13 as medium effects, and values >.13 as large effects (see Cohen, 1988).

Posttest

For the posttest, a 3x2 analysis of covariance was performed, using the control measure 'average physics grade in the last two years in high-school' as a covariate and the between-subjects factors prior-knowledge activation (none, create-and-label-the-lines, label-the-lines) and level of expertise (physics student, student at high school). The covariate met the homogeneity of regression slopes requirement and had a statistically significant effect on the posttest, $F(1,81) = 22.43$, $p < .05$. Means and standard deviations for the different groups and levels of expertise are shown in table 1.

Table 1: Means and standard deviations (in parentheses) of the learning outcomes

	No prior-knowledge activation	Creating-and-labeling lines	Labeling provided lines
High-school students	5.73 (2.71)	6.89 (3.71)	8.89 (4.07)
Physics students	9.07 (2.45)	12.33 (2.89)	10.97 (3.58)

Does prior-knowledge activation with concept maps improve results in the posttest? Consistent with our hypothesis, an ANCOVA yielded a statistically significant difference for an a priori defined contrast (the pooled activation groups vs. baseline group) in favor of prior-knowledge activation, $F(1,81) = 7.47$, $p < .05$, $\eta^2 = .08$ (medium effect).

Does a higher level of expertise improve results in the posttest? As was hypothesized, an ANCOVA test for differences in group means yielded a statistically significant difference for expertise in favor of the physics students, $F(1,81) = 7.89$, $p < .05$, $\eta^2 = .09$ (medium effect).

Do participants with a higher level of expertise benefit from low-coherent prior-knowledge activation, while participants with a lower level of expertise benefit from high-coherent prior-knowledge activation? Figure 3 shows the corresponding significant interaction, $F(1,81) = 5.02$, $p < .05$, $\eta^2 = 06$: Physics students performed better when creating-and-labeling lines while high-school students performed better when just labeling provided lines. This interaction effect was of medium practical significance, $\eta^2 = .06$ (medium effect).

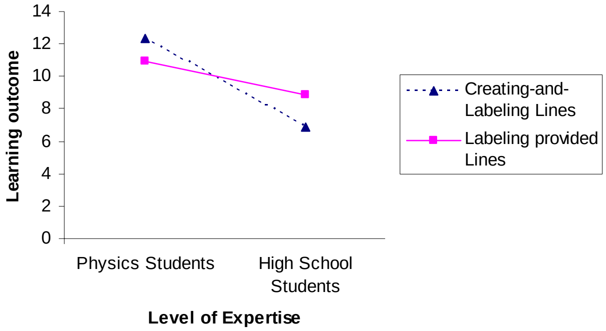

Figure 3: Learning outcome performance of university physics-major and high-school students (means).

Navigation in the Hypertext and Perceived Goal-Orientation

For the navigation and the perceived goal-orientation, a 3x2 analysis of variance was performed with the factors prior-knowledge activation (none, create-and-label-the-lines, label-the-lines) and level of expertise (physics student, student at high school). The control variable 'average physics grade in the last two years in high-school' did not show a significant relation with the dependant measures and therefore was excluded from this analysis.

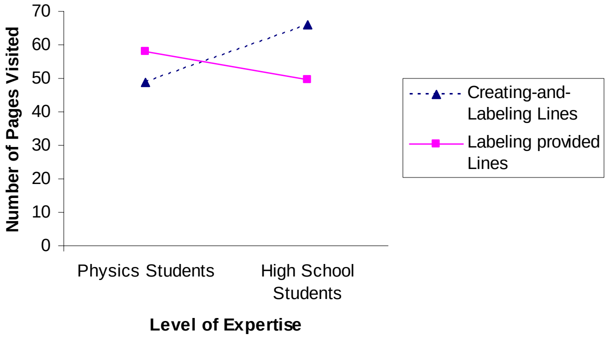

Figure 4: Number of pages visited in the hypertext (means).

Does prior-knowledge activation influence the number of pages visited in the hypertext? Log-files of six subjects were not recorded due to technical difficulties. ANCOVA yielded a statistically significant difference in the number of pages visited for an a priori defined contrast (the pooled activation groups vs. baseline group), $F(1,76) = 18.75$, $p < .05$, $\eta^2 = .20$ (large effect). Participants in the groups with prior-knowledge activation ($M = 56.04$, $SD = 22.21$) visited less pages than participants in the baseline group ($M = 79.50$, $SD = 30.03$). In addition we found that physics students visited fewer pages after the low-coherent prior-knowledge activation while high-school students visited fewer pages after the high-coherent prior-knowledge activation (Figure 4). The corresponding interaction effect reached only the 10%-level of significance, $F(1,75) = 3.91$, $p < .1$, $\eta^2 = .05$ (small effect), so that it has to be interpreted with caution.

The reduced number of pages visited in the conditions with prior-knowledge activation is also reflected by the self-rating of goal-orientation, ANCOVA test for differences in group means yielded a statistically significant difference in favor of prior-knowledge activation, $F(1,81) = 14.29$, $p < .05$, $\eta^2 = .15$ (large effect). Participants with prior-knowledge activation ($M = 3.50$, $SD = 1.25$) perceived themselves more goal-oriented than participants in the group without prior knowledge activation ($M = 2.47$, $SD = 1.22$) on the rating scale ranging from one to six. In addition, we found that physics students rated themselves as less goal-oriented ($M = 2.83$, $SD = 1.27$) than high-school students ($M = 3.43$, $SD = 1.34$) $F(1,81) = 6.30$, $p < .05$, $\eta^2 = .07$ (medium effect).

Effects on Self-Questioning

To investigate effects of different prior-knowledge activation on self-questioning, a 2x2 analysis of variance was performed using prior-knowledge activation (create-and-label-the-lines, label-the-lines) and level of expertise (physics student, student at high school) as factors. We found a significant main effect of different prior-knowledge activation on *model-construction-questions*. Participants creating and labeling lines asked more model-construction-questions ($M = .52$, $SD = .74$) than their peers labeling provided lines ($M = .13$, $SD = .40$) $F(1,54) = 5.98$, $p < .05$, $\eta^2 = .10$ (medium effect). In addition, we found an effect of different prior-knowledge activation on *reflection about single relationships*. Participants creating-and-labeling lines asked less reflection questions ($M = 1.00$, $SD = 1.11$) than their peers labeling provided lines ($M = 1.89$, $SD = 1.92$) $F(1,54) = 4.54$, $p < .05$, $\eta^2 = .08$ (medium effect). There were no effects of different prior-knowledge activation on organization and definition questions.

Finally, we obtained an effect of expertise on organization-questions. Physics students asked less organization questions ($M = .17$, $SD = .42$) than high-school students ($M = .52$, $SD = .78$) $F(1,54) = 4.75$, $p < .05$, $\eta^2 = .08$ (medium effect). There were no interactions between the level of expertise and the type of prior-knowledge activation on questions.

Discussion

The first three research questions about effects of prior-knowledge activation on learning outcomes can be answered as follows: First, prior-knowledge activation with concept maps improves learning outcomes compared to a baseline condition without prior knowledge activation. Second, as to expect, learners with a higher level of expertise outperformed learners with a lower level of expertise (Chi, Feltovich, & Glaser, 1981). Third, we found empirical support for an interaction between the level of expertise and the coherence of prior-knowledge activation, indicating that participants with a higher level of expertise benefit more from low-coherent prior-knowledge activation, while participants with a lower level of expertise benefit more from high-coherent prior-knowledge activation.

The results of the last three research questions provided first insights into the processes between low- and high-coherent prior-knowledge activation and learning outcomes. Prior-knowledge activation reduced the number of pages visited in a subsequent content-related hypertext also showed a trend towards an interaction between the level of expertise and the coherence of prior-knowledge activation: Physics students visited fewer pages after the low-coherent prior-knowledge activation while high-school students visited fewer pages after the high-coherent prior-knowledge activation. Learners with prior-knowledge activation perceived themselves as more goal-oriented than the learners without prior-knowledge activation. Reflecting subsequently after prior-knowledge activation, participants in the low-coherent prior-knowledge activation condition asked more model-construction questions than their peers in the high-coherent prior-knowledge activation condition, but did less reflection about single relationships.

The beneficial effect of prior-knowledge activation is evidence for the theoretical claim that it is not enough to assume that prior-knowledge is activated automatically, for example, while reading an instructional text. Related to this ‘automatic view’ is an extended common-strategy hypothesis (Lorch & Lorch, 1995), assuming that mature readers automatically activate prior-knowledge and attempt to encode the top-level structure of a text. But as both, learners with a high-level of expertise and learners with a lower level of expertise benefited from prior-knowledge activation, the results do not support the common-strategy hypothesis.

One theoretical explanation for the general beneficial effect of prior-knowledge activation may be the intentional activation of specific concepts from long term memory. This may have focused learners on the most important aspects, and is based on assimilation theory and the assumption that prior-knowledge activation allows learners to add more information to long-term-memory because more ‘anchors’ for assimilation are activated (for reviews see R. Mayer, 1979; Preiss & Gayle, 2006). Although this theoretical explanation is in accordance with the general beneficial effect of prior-knowledge activation, it is not able to explain the interaction between different levels of expertise and the coherence of prior-knowledge activation - in particular as both, the low- and high-coherent prior-knowledge activation used the same concepts. As physics students performed better in a condition with less information (no connection lines between provided concepts) this may only be explained by different cognitive and metacognitive processes elicited through the low-coherent and high-coherent prior-knowledge activation. One explanation may be the following view about prior-knowledge activation: In addition to the automatic activation of prior-knowledge, and the activation of specific concepts, carefully designed prior-knowledge activation may establish a distinctive *'mental set'* (see Luchins, 1942; Schuck, 1981) for the learning phase. On a broader level, the '*mental set*' should determine what kind of information is focussed on. For example if learners focus on definitional content, more definitions should be recalled, if the attention is directed on relations between concepts, more relations should be recalled. On a finer level, different activities using the same concepts may elicit different cognitive and metacognitive processes (Gurlitt et al., 2006), different processing of the information during learning, and different learning outcomes. Further complicating this issue, only learners with just the right degree of expertise may be able to benefit from different processes elicited during prior-knowledge activation. This view about establishing a distinctive mental set with specific prior-knowledge activation is also supported by the differential amount of model-construction questions vs. reflections about single relationships after low- and high coherent prior-knowledge activation. Finally, the trend in the number of pages visited in the hypertext also tentatively supports the claim to consider both, the coherence of prior-knowledge activation and the level of expertise.

While the above view is focused on the activity of prior-knowledge activation, it is related to the strategy-switch hypothesis (Lorch & Lorch, 1995). This hypothesis stated that signals (e.g., topical overviews, headings, or summaries) may facilitate learners to switch their reading strategies from a list-learning approach to a structure strategy, focusing their attention towards the top-level structure of the text (Lorch & Lorch, 1995).

Summarizing, the interaction between the level of expertise and the coherence of prior-knowledge activation, extends coherence effects found in text comprehension (McNamara et al., 1996; McNamara & Kintsch, 1996) towards prior-knowledge activation. Further, the interactions between expertise and the mapping-task used for prior-knowledge activation support the hypothesis that different mapping-tasks elicit qualitatively different processes, analogous to the research from Ruiz-Primo et al. (2001) and Gurlitt et al. (2006). Generalizations of these results should be interpreted carefully with respect to the realized topic, mapping tasks, learning outcomes, and type of learners.

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