Individual Differences in Concept Mapping when Learning from Texts

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Abstract

Concept maps consist of nodes representing concepts and links representing the relationship between the concepts. Various studies showed that concept mapping fosters meaningful learning. However, little is known about the specific cognitive processes that are responsible for such mapping effects. A thinking-aloud study was carried out to analyze the relations between cognitive processes during concept mapping and learning outcomes (38 university students; 17 male, 21 female, mean age 23.8). Additionally, characteristics of the concept maps the learners produced were included in the analysis. The results emphasize the importance of explicating the relationship between the concepts by labeling the links as well as the importance of content-related planning and controlling of the mapping process. The results provide useful hints of how to develop a training method for beginners in concept mapping.

Keywords: Concept Maps, Text Learning, Thinking Aloud.

Introduction

Concept mapping is a method for representing knowledge graphically. Nodes represent concepts and labeled links represent the relations between the concepts. Based on Ausubel's assimilation theory of cognitive learning (Ausubel, Novak, & Hanesian, 1978), concept maps visualize the hierarchy and relationships of concepts. Through the construction of a concept map, meaningful learning can be assisted (Novak, 1990).

Novak (1995) describes a multitude of possible areas of application, for example, concept maps can assist the preparation of lessons and the sequence of topics presented. They serve as a basis for discussions and they can be used as a tool for knowledge evaluation. Furthermore, concept maps can assist learning from texts. It is this latter application of mapping that is focused on in this study.

What makes Concept Mapping so Beneficial?

Due to the affordance of expressing notions in nodes and relations in links, concept maps foster elaboration processes (Weinstein & Mayer, 1986). Often learners have to integrate new information with their prior knowledge in order to determine what concepts are important and whether and how they interrelate. This is what we call the *elaboration function* of maps.

Weaver and Kintsch (1991) found that macropropositions which contain the top-level information of a text is recalled in more detail in long-term experiments. Maps can enhance the acquisition and retention of macrolevel ideas (O'Donnell, Dansereau, & Hall, 2002). Learners have to appraise the importance of concepts in order to decide whether they should integrate them in their concept map. Thus, learners concentrate on the most relevant macrostructure information of their learning topic. This is called the *reduction function* of maps.

As concept maps require the externalization of knowledge, working memory is offloaded and the construction of coherence is facilitated (Kintsch, 1998). Spatial arrangements can emphasize that concepts belong together. The use of similar colors can represent that certain concepts share a relationship. Additionally, labeling the links connecting the nodes emphasizes the kind of relationship between concepts. This is called the *coherence function* of concept maps.

Also, metacognitive processes are supported. Knowledge and comprehension gaps can become obvious when constructing and explicating relations between concepts, (e.g., Chi, Bassok, Lewis, Reimann, & Glaser, 1989). At best, learners can overcome these gaps when they are aware of them. This is what we call the *metacognitive effect* of mapping.

Beginners' Difficulties in Concept Mapping

A variety of studies have demonstrated the effectiveness of concept mapping as a learning method, including a meta-analysis of 19 quantitative studies by Horton et al. (1993). The authors found a generally positive effect on knowledge acquisition.

Although concept mapping fosters learning and understanding, learners are easily overwhelmed by the demands of mapping. Participants in a study by Reader and Hammond (1994) learned from hypertext either by note-taking or by concept mapping. Even though learners in the concept mapping condition performed better, qualitative analyses showed that they failed to structure and integrate the information provided by the hypertext in a favorable way. The learners were not able to use the advantages of the method to the expected degree.

Concept mapping without training is very difficult for beginners. As O'Donnell et al. (2002) state, training is a key factor in producing favorable outcomes. In order to cope with beginners' difficulties in using concept maps for learning from texts, a few training studies have been conducted. For example, Chang, Sung, and Chen (2002) compared the learning outcomes of students after either correcting worked-out concept maps with mistakes, constructing their own concept maps after a training session, or constructing concept maps without training. The students learning by correcting concept maps achieved the best results in a post-test on text comprehension. Students learning by constructing a map without a training session performed the worst. These results demonstrate that beginners in concept mapping are often overwhelmed with the demands of the mapping. Even after a training session, students still could not successfully cope with the demands.

Compared to constructing concept maps, the use of worked-out concept maps did show some positive effects on the learning outcomes (e.g., Chang et al., 2002). However, this method of introducing concept mapping is quite laborious for instructors to use. Additionally, in the long term it is preferable that learners construct their own maps.

Currently, an effective method for training students how to use concept mapping that is efficient and directed to the typical needs of beginners in mapping is missing. This is also due to the fact that there is little empirical evidence indicating which cognitive processes are crucial for successful mapping and which deficits beginners have in this respect. Most studies just report some anecdotes of the learners' difficulties during concept mapping (e.g., Jonassen, Beissner, & Yacci, 1993). Knowing beginners' specific deficits is necessary in order to develop effective training.

Research questions

In order to develop a strategy for teaching concept mapping that is adapted to the learners' needs, it is important to first explore factors that hinder and foster learning by concept mapping. Thus, the aim of the present study was to analyze individual differences between learners with respect to factors that can determine learning outcomes. Therefore, data concerning the cognitive processes elicited by concept mapping have been collected. It is assumed, that especially those cognitive processes that refer to the elaboration function, the reduction function, the coherence function, and the meta-cognitive effect of mapping foster good learning outcomes. Thus, the cognitive processes elicited by concept mapping and concept map characteristics were considered as factors determining learning. Furthermore, it is analyzed whether concept mapping as a follow-up activity to reading has a positive effect on learning at all. The following specific research questions were addressed:

1. Does concept mapping have a positive effect on learning?
2. To what extent are individual characteristics of the concept maps related to the learning outcomes?
3. Are the learning outcomes associated with the quality of the cognitive processes during the concept mapping?

Method

Participants

Thirty-eight students (17 male, 21 female, mean age 23.8 years) from the University of Freiburg participated in the experiment. All were native speakers of German. As one participant did not follow the mapping instructions, he was excluded from the analysis.

Materials

Newspaper Articles on Stem Cells The learning contents were provided in six newspaper articles on stem cells. This topic was chosen because most students are relatively unfamiliar with the specifics related to this issue. Yet it is a topic that is very complex (i.e., requires integration of biological and ethical knowledge) and is widely discussed in Germany. Providing more than one source increased the motivation (necessity) to engage in a follow-up activity after reading.

Mapping Software The participants worked with the Easy Mapping Tool, a software especially developed for concept mapping (see http://www.cognitive-tools.de for further information). The application of the software was easy to learn. It provided different forms and colors for nodes. Links to connect the nodes could be labeled.

Learning Assessments Two tasks measured the learning outcomes. First, a post-test consisting of seven multiple choice questions on stem cells provided a measure of the extent to which the learners integrated the information in the articles. In order to answer the single *integration-test* questions, integration of the knowledge of at least two articles was required.

Second, the students were asked to answer the question "What are stem cells and what could be done with them?". The *stem-cell question* had to be answered (1) in the pretest and (2) had to be revised after reading the articles, (3) as well as after producing the concept map. Comparing the revisions of the answer before and after concept mapping provided information on the changes in the participants' knowledge on stem cells.

Procedure

In the pretest phase, the participants first responded to a questionnaire about their experiences with concept mapping and some demographic questions. Afterward, they answered the stem-cell question to assess their prior knowledge about the learning topic (i.e., stem cells). Then, they were given six different newspaper articles dealing with stem cells. Participants were provided enough time to read each article once. After reading them, they had to revise their answer to the stem-cell question. Next, the participants produced a concept map about the topic of stem cells. To this purpose, they received an introduction into concept mapping. The terms 'node' and 'link' were explained and an example of a concept map was provided. No further hints for producing the concept maps were given. The maps had to be produced with the mapping software Easy Mapping Tool and the participants received a brief instruction in how to use the software. Further help with the software was provided on demand. Time for concept mapping was limited to 30 minutes. The participants were encouraged to use the newspaper articles as a basis for constructing their maps. They were asked to simultaneously verbalize their thoughts during the construction of the concept map. According to Ericsson and Simon (1993), participants were just asked to "keep talking", no further advice was given to avoid reactivity effects.

After 20 seconds of not speaking, they were again reminded to keep talking. After concept mapping, the participants had to revise their answer on the stem-cell question again. Finally, they worked on the integration test.

Coding Schemes

Different coding systems were developed for the answers to the stem-cell question, for the thinking-aloud protocols, and for the analysis of the maps.

Coding of the Answers to the Stem-Cell Question The answers to the *stem-cell question* were segmented into propositions and classified into three distinct categories. Interrater-reliability was computed using Cohen's Kappa, $\kappa = .78$.

(1) *Non-text.* This category was coded when a statement was not part of the newspaper articles about stem cells that the participants read.

(2) *Correct.* The proposition was coded as correct when it contained information that was included in the newspaper articles and was reproduced correctly.

(3) *Incorrect.* The information was included in the newspaper articles but was reproduced incorrectly.

To obtain a measure of the increase of knowledge and understanding through concept mapping, the difference of correct propositions before and after concept mapping was calculated (increase of correct propositions). Additionally, the decrease of incorrect propositions was calculated by subtracting the amount of incorrect propositions after concept mapping from the amount of incorrect propositions before concept mapping (decrease of incorrect propositions).

Thinking-Aloud Protocols The thinking-aloud protocols were segmented into verbal units. A verbal unit comprised a segment of thoughts about one specific content, for example, thoughts about a concept or a pair of concepts. A coding system for the thinking-aloud protocols was developed. The main categories were as follows:

(1) *Elaboration of Concepts*. The learner connected his own knowledge with the learning content by generating examples or paraphrasing (Weinstein & Mayer, 1986). This category refers to the elaboration function of concept maps (e.g., "So, if I took one of my skin cells and put the nucleus in an ovum, an embryo would grow that is just like me. Its stem cells would fit me perfectly.").

(2) *Organization.* This category was coded when a statement refers to (a) the importance of a concept, or (b) the hierarchical classification of a concept (Weinstein & Mayer, 1986) (reduction function; e.g., "Embryonic stem cells are an important sub-category of stem cells. I'm going to make a node and write embryonic stem cells in it.").

(3) *Relationships.* The learner clarifies the relation between concepts by thinking about how to label the links, using different colors for groups of concepts, and by structuring the concept map in a way that accentuates groups of concepts belonging together (coherence function; e.g., "There's a connection between stem cells and pre-implantation diagnostics. You need stem cells for the PID. I'm going to label this link with are examined.").

(4) *Negative Monitoring.* This category contains utterances about comprehension problems (Chi et al., 1989) (metacognitive function; e.g., "I just don't get this thing with the embryonic germ cells. Are they the same as stem cells, or what's the difference?").

(5) *Positive Monitoring.* The learner states his or her understanding of the contents (metacognitive function; e.g., "Yes, now I got it.").

(6) *Planning and Controlling.* Verbal units referring to the progress of the concept map like planning the next steps and controlling whether contents are missing have been coded with this category (e.g., "I didn't really explain the characteristics of stem cells. That's what I have to do next.").

(7) *False Statements.* Incorrect statements of the participants were coded in this category.

(8) *Activity Report.* This category was coded when the learner just described what he was doing without referring to the contents (e.g. "Now I make a node here and connect it with such an arrow to the other one.").

(9) *Reading Aloud.* This category was scored for reading the articles on the stem-cell topic.

(10) *Non-Content Problems.* The learner talked about general problems with the mapping method, the mapping software, or the demands of thinking aloud (e.g., "I'm not used to thinking in nodes. If I learned this stuff on my own I would perhaps make a table.").

The coding categories were distinct and there were no inclusions of segments. Good interrater-reliability was obtained for the coding of the verbal data (Cohen's $\kappa = .73$).

Concept Maps Following Rafferty and Fleschner (1993), a coding system for the participants' concept maps was developed. Rafferty and Fleschner presented a method to evaluate concept maps by scoring the number of valid relationships between concept-nodes, and the number of cross-links between distinct segments. In the present study, the scoring system was slightly modified. The following concept map characteristics were analyzed:

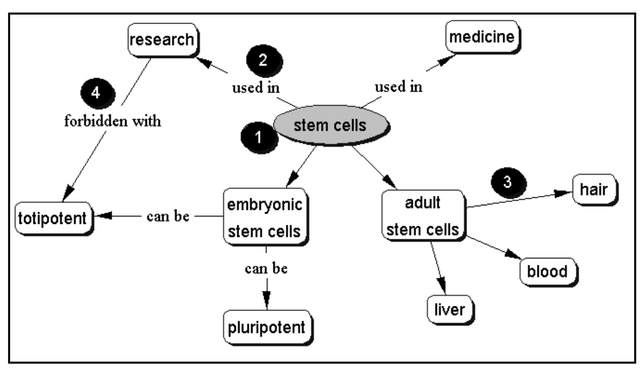

Figure 1: Concept map on stem cells.

(1) *Number of concept nodes.* All the nodes in the concept map were counted (see number 1 in Figure 1 for an example).

(2) *Number of correctly labeled links.* All the links that were correctly labeled to connect the concept-nodes were counted (see number 2 in Figure 1).

(3) *Number of unlabeled links*. All the links between concept nodes that were not labeled were counted in this category (see number 3 in Figure 1).

(4) *Number of cross-links.* Cross-links are links that connect the segments of a map. The cross-links were counted (see number 4 in Figure 1 for an example).

Results

The majority of participants (63%) did not know what concept maps were prior to the experiment. There were no differences in the learning outcomes between learners who knew about concept maps and those who had not heard of this learning strategy before, $t(36) = -1.07$, *ns*. Thus, we did not have to control for prior experience in mapping.

Knowledge Acquisition

In order to confirm the benefits of concept mapping for learning, we analyzed the answer to the stem-cell question. Participants first revised their answers to the stem-cell question after reading the texts and revised it again after concept mapping. Figure 2 shows the means of correct and incorrect propositions at the three different measuring times.

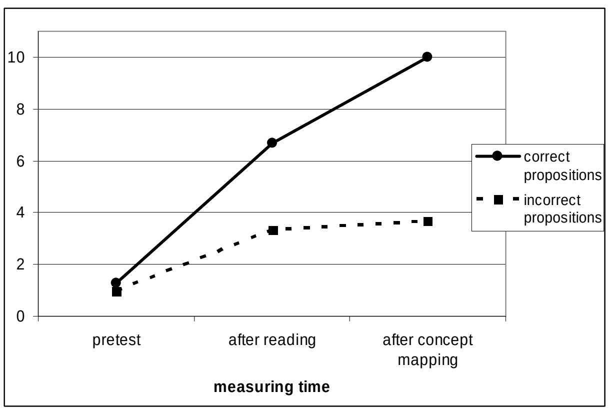

Figure 2: Mean (SD) of correct and incorrect propositions at the three measurement points.

An ANOVA with repeated measurements proved the increase of correct propositions over the three measuring times significant, $F(1.7, 60.2) = 191.46$, $p < .001$, $\eta^2 = .84$. The increase of incorrect propositions over the three measuring times was significant too ($F(1.6, 59.3) = 51.58$, $p < .001$, $\eta^2 = .59$).

Although the participants increased their knowledge of stem cells through reading, a further increase of $M = 3.3$ correct propositions after concept mapping was observed ($SD = 2.11$). This increase was statistically significant ($F(1, 36) = 91.9$, $p < .001$, $\eta^2 = .72$). This increase of correct propositions is consistent with the findings that concept maps foster learning outcomes (e.g. Horton et al., 1993).

The number of incorrect propositions after concept mapping did not significantly change, $F(1, 36) = 2.72$, *ns*. Thus, concept mapping neither helped the learners to reduce the amount of mistakes they made in their answer to the stem-cell question nor did they make new mistakes after concept mapping. Nevertheless, the change of incorrect propositions ranged from -3 to +2 for different individuals. Obviously, some learners managed to correct mistakes they made before concept mapping, whereas others made up to two new mistakes. In the following, we will use the variable 'decrease of incorrect propositions' in order to express the extent to which incorrect propositions increased or decreased in individual learners after mapping.

Concept Map Characteristics

The concept maps that the learners produced were analyzed according to the number of concept nodes, the number of correctly labeled links, the number of unlabeled links, and the number of cross-links. Table 1 provides an overview of the correlations of the concept map characteristics with the learning outcomes.

Table 1: Correlations between the concept map characteristics and learning outcomes.

	Learning Outcomes		
	Integrationtest	Increase of correct propositions	Decrease of incorrect propositions
Concept nodes	.33*	.15	.28
Correctly labeled links	.53**	-.06	.45**
Unlabeled links	-.33*	.20	-.15
Cross links	-.07	-.07	.19

Note. *$p < .05$; **$p < .01$.

The concept maps the learners produced contained on average 18.41 nodes ($SD = 4.49$). The number of concept nodes correlated significantly with the participants' performance on the integration test. No correlation was found with the increase of correct propositions and with the decrease of incorrect propositions (Table 1).

The mean for correctly labeled links was 11.86 ($SD = 6.15$). The more correctly labeled links in the maps, the better the participants performed on the integration test (Table 1). Also, the decrease of incorrect propositions was the greatest, the more correctly labeled links were included in the map. Although labeling the links was not related to more correct conclusions in the last revision of the stem-cell question, the participants who focused more on labeling were likely to correct the mistakes in their answer.

The average number of unlabeled links was $M = 4.68$ ($SD = 6.06$). Participants who were unlikely to label the links between the nodes performed worse on the integration test. (Table 1). No correlation was found with the increase of correct propositions and with the decrease of incorrect propositions.

Cross-links appeared relatively seldom ($M = 1.76$, $SD = 2.00$). As Table 1 shows, the number of cross-links did not correlate with the learning outcomes.

Thus, the concept map characteristics that related most to the learning outcomes was the number of correctly labeled and unlabeled links. Further qualitative analysis showed that the unlabeled links connected the concept nodes quite adequately. However, the participants just did not seem to reflect on the relation to a sufficient degree. This interpretation is also supported by the results of the thinking-aloud protocols, as reported in the following.

Cognitive Processes during Concept Mapping

The thinking-aloud protocols were segmented into verbal units and coded in ten distinct categories. Table 2 presents an overview of the results concerning the correlations of the cognitive processes during concept mapping and the learning outcomes.

Table 2: Correlations between the students' cognitive processes and their learning outcomes.

	Learning Outcomes		
	Integration test	Increase of correct propositions	Decrease of incorrect propositions
Elaboration	-.02	.05	.42*
Organization	-.26	-.06	-.05
Relationships	.39*	-.11	.03
Negative Monitoring	-.40*	.10	-.05
Positive Monitoring	-.19^{+}	.28	.23
Planning and Controlling	.58**	-.07	.13
False Statements	.04	.12	.29^{+}
Activity Report	-.49**	.05	-.40*
Reading Aloud	.02	.13	.08
Non-content Problems	-.10	-.01	-.08

Note. $^{+}p < .10$. $*p < .05$. $**p < .01$.

As Table 2 shows, the elaboration of concepts neither correlated with the integration test nor with the increase of correct propositions in students' answers to the stem-cell question after concept mapping. However, the more elaborations the participants made, the greater the decrease in incorrect propositions. By connecting the new information presented in the newspaper articles with their already existing knowledge, the participants were obviously able to correct mistakes when revising their answers on the stem-cell question. The organizational activities were not related to learning outcomes (Table 2).

With respect to the category 'relationships', the more the learners reflected on relationships between the concepts, for example, by thinking about how to label the links, or using different colors for groups of concepts, the better they performed on the integration test (Table 2). This is consistent with the finding that unlabeled links were associated with poor performance on the integration test. The explication of relationships did not correlate with the increase of correct propositions or with the decrease of incorrect propositions.

Participants who were more likely to express their comprehension problems (i.e., negative monitoring) achieved worse results in the integration test (Table 2). This suggests that learners seemed to have recognized their knowledge gaps, but were not able to overcome these problems. Negative monitoring was significantly related to the explication of relationships (r = -.56, p < .001). Possibly, the comprehension problems hindered the learners articulating the relationships between concepts which impaired learning.

Positive monitoring was related to a higher increase of correct propositions, at least at the 10%-level of significance (Table 2). Apparently the learners' self-estimation of their understanding was strongly associated with the actual increase of correct knowledge.

Planning and controlling the mapping process was significantly correlated to the learning outcomes as measured by the integration test (Table 2). Planning the next steps and checking whether there were contents missing or whether the concept map was complete seemed to be very important strategies for learning by concept mapping.

False statements correlated with the decrease of incorrect propositions at the 10%-level of significance (Table 2). This could be a result of augmented planning and controlling processes, as there was a positive correlation between the amount of planning and controlling and false statements (r = .42, p = .01). The amount of false statements, however, did not correlate with negative monitoring (r = .07, *ns*). The participants were apparently not able to overcome their comprehension problems when they recognized they had problems understanding the information presented. Nevertheless, they were able to recognize and overcome their errors when they controlled for the correctness of their concept maps. This result also emphasizes the importance of planning and controlling for the construction of concept mapping.

Devoting much attention to what they were doing without referring to the learning contents on the one hand impaired the performance in the integration test on stem cells, and on the other hand prevented learners from detecting and correcting their mistakes (cf. 'activity report' in Table 2). This finding suggests that preoccupation with just the 'design' of the concept map without directing attention to the kind of information that was displayed in the map should be avoided in order to ensure favorable learning outcomes.

No correlations were found between the different learning outcomes on the one hand and reading aloud as well as non-content statements on the other hand (Table 2). Although the more the participants read, the more they had the possibility to deepen their knowledge on stem cells without using concept mapping as a learning strategy, just reading had no impact on learning (see 'reading aloud' in Table 2). Finally, differences in learning gains were not found when considering participants' problems in using the mapping software, the mapping process itself, or the demands of thinking aloud (see 'non-content problems' in Table 2).

Discussion

The aim of this study was to examine interindividual differences between learners constructing concept maps as a strategy to learn from texts. To this purpose, cognitive processes elicited by concept mapping were analyzed as well as concept map characteristics.

The effectiveness of concept mapping for learning was once more confirmed by the results of this study. As a variety of studies (e.g., Horton et al., 1993), we also found a substantial increase of knowledge after constructing a concept map. This is particularly interesting as the participants learned from six separate texts only partially overlapping in their information. As Britt, Perfetti, Sandak, and Rouet (1999) showed, learners often cannot integrate information from multiples texts to a substantial degree. Concept mapping could be a useful tool to foster learning especially from multiple sources.

One important finding with respect to the factors correlated to learning outcomes is that efforts to figure out the precise relation between concepts were especially crucial. This was supported by the analysis of the thinking-aloud protocols as well as by the concept maps the learners constructed.

In addition, processes of content-related planning and controlling are associated with preferable learning outcomes. These processes seemed to help learners to recognize the mistakes they made and to overcome their lack of comprehension. Further in-depth analyses of the present data will be carried out in order to test this assumption.

Describing the pure technical design of the concept map a lot without referring to the contents that were represented was detrimental to learning. Paying attention to the information displayed in the concept map is much more important than just 'making nodes' and 'connecting nodes'.

Of course, given the correlational character of this study, it is possible that the differences in the learning outcomes are not a result of the different concept mapping strategies but of general abilities. Therefore it is possible that a training in concept mapping cannot overcome the limitations resulting from restricted abilities. Thus it is important to conduct a training study that proves the relevance of the presumably beneficial and hindering factors found in this study.

So far, the present results lead to the following recommendations:

- Instruct learners to put special attention on carefully labeling their links.
- Emphasize the relevance of planning the mapping process and controlling the improvement of the concept map.
- Guide learners to shift their attention from the pure technical design to the learning contents as far as possible.

In a next step, a corresponding training for beginners in concept mapping will be developed. Further studies will test the effectiveness of such a training.

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