Concept Mapping: Connecting Educators
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FAULTS IN CONCEPT MAPPING: A MATTER OF TECHNIQUE OR SUBJECT?

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Abstract. Concept maps appear to reflect a user's knowledge achievement. For examining the impact of a subject's difficulty or rather Cognitive Load on concept mapping within an educational implementation, we developed a lesson about two differently complex subject matters. Furthermore, we intended to verify whether concept mapping is an acceptable knowledge test or not. A-level 6th graders produced individual concept maps with regard to a taught subject matter immediately after a computer-aided biology lesson. Each group produced a concept map about both implemented subject matters. Altogether 283 students participated by producing 138 concept maps about the subject matter "Polliwog to Frog" (A) and 136 about the "Ecosystem Lake" (B). We analysed the maps' complexity as well as the types of faults and we correlated the individual student's knowledge scores with his/her concept map's complexity. Students in general produced more complex concept maps about the easier subject matter (A), and they had difficulties to verbalize the appropriate connections of the complex subject matter (B). We found significant correlations between the knowledge scores and the actual complexity of a concept map: The actual complexity underestimates a student's knowledge in general. The conclusions for an implementation in a classroom will be specifically discussed.

1 Introduction NEW

Concept Mapping (CM) was frequently discussed as an appropriate method for knowledge testing (Novak 1984, Horn 2003, Schaal 2006). It represents a rather complex approach in assisting to develop visual presentations of complex coherences and in reflecting individually newly-acquired knowledge (Stracke 2004). It has some demand on the limited information capacity of the mental activity of working memory labelled as Cognitive Load (CL) (e.g. Baddeley 1992). Sweller, Merrienboer, Paas (1998) assume three CL components as (i) intrinsic load caused by the content complexity, (ii) extraneous load caused by the instructional mode, and (iii) germane load necessary for individually processing information towards long-term memory. As all three components are assumed to be additive (Sweller 2006) an increase of component (i) and/or (ii) without decrease of the other would cause a Cognitive *Over*load. Capacity for (iii) germane load would be reduced and consequently cognitive learning of the subject matter. Applied to the CL theory (i) intrinsic load is the subject matter and (ii) extraneous load is referring to the lesson within the consolidation phase, e.g. concept mapping.

In our study, concept mapping was spontaneously introduced to the students as a consolidation phase in a 6th grade computer-supported biology lesson. In order to check the hypothesis that CM provides an appropriate knowledge test we correlated post-test knowledge scores and actual complexity (AC) of concept maps. To investigate the effect of CL we altered (i) intrinsic load with two differently difficulty subject matters and compared students' achievement. Therefore we designed a lesson about two differently difficulty subject matters. CM was introduced to the novice students as a consolidation phase. For a reduction of cognitive overload (e.g. Baddeley 1992; Scharfenberg, Bogner, Klautke 2007) component (ii) we simplified the design by implementing specific pre-structures with pre-defined items (Nückles 2004) (Table 1). None of the linking phrases were pre-defined.

2 Data collection

Altogether 283 6th graders participated in our study, a total of ten Bavarian high school classes (highest stratification level [=Gymnasium]). The concept mapping was introduced to the students as a knowledge consolidation phase after a completion of a computer-supported lesson. Students were novices with regard to the method itself and that is why we introduced the concept mapping with a separate ten-minute preface: for this purpose the teacher functioned as a tutor by presenting an example unrelated to our subject content. We selected two subject matters for its implementation; students had 35 minutes to complete the poster in dyads. Both subject contents differed in term of its content and its quantity. The first subject (A) dealt with "Polliwog to Frog" consisting of 18 pre-defined items; the second (B) was more complex and dealt with the "Ecosystem Lake" consisting of 24 items (Table 1). Students were free to add more items. Linking phrases were not specified. For the afterwards analysis all hand-written concept map posters were digitised with MaNet® 1.6.1. (© MaResCom GmbH) (Figure 1). Previous knowledge and changes in standard of knowledge were measured by means of pre-test (K1) two weeks before and post-test (K2) immediately after the lesson.

(A) Polliwog to Frog	polliwog	larva of frogs	spawn	eggs	cluster	brood care
	march	metamorphosis	gills	lung	insects	algae
	foreleg	hind leg	singing	frog	mating	tail
(B) Ecosystem Lake	cohabitat	biocoenosis	temperature	biotope	oxygen	consumer
	herbivore	abiotic factors	biotic factors	bacteria	biomass	producer
	carnivore	photosynthesis	decomposer	animals	light	destruents
	1st order	2nd order	ecosystem	plants	habitat	user

Table 1: Pre-defined Items of subject (A) “Polliwog to Frog” and (B) “Ecosystem Lake”

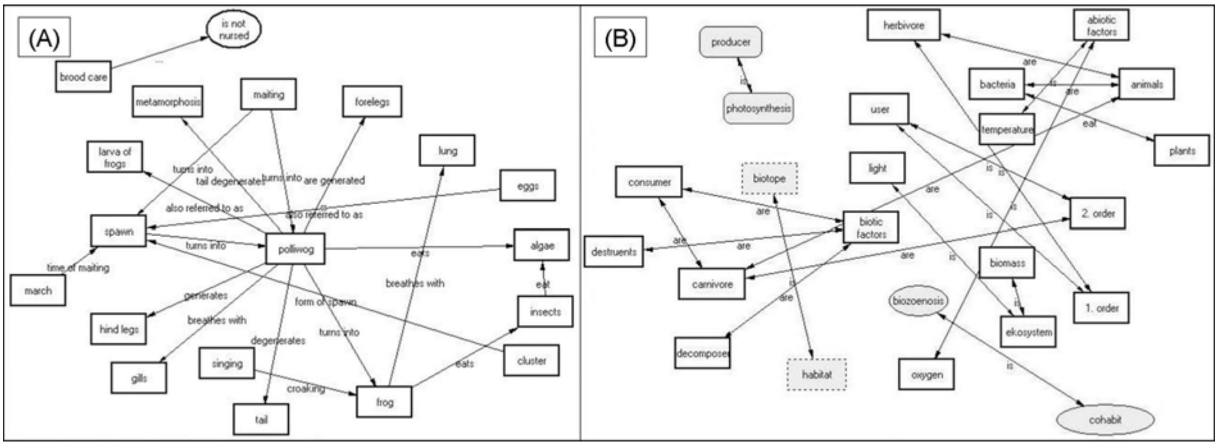

Figure 1. Examples for digitised, not corrected concept maps about subject (A) “Polliwog to Frog” and (B) “Ecosystem Lake” annotation: in (A) round frame marks not pre-defined item, added by student; in (B) different frames mark different subnets

3 Analysis of concept maps

3.1 Analysis of objectivity

The objectivity of analysis is guaranteed, if its test analysis is not influenced by the analyzer. This is taken for granted, if different persons come to same results of correction (Bortz, Döring 1995). Therefore, the correctors analyzed 10% of the concept maps a second time after four weeks as well as a second corrector analyzed the same 10% independently. The comparison of the results of two correctors tests the objectivity of the interpretation of the connections (Ingenkamp 1992). The results of all correctors were compared to calculate objectivity by Cohen’s kappa- coefficient of the cross tabulation (Zöfel 2002) (Table 2).

$$\text{kappa} = \frac{n \cdot \sum_{i=1}^{k} d_i - \sum_{i=1}^{k} z_i \cdot s_i}{n^2 \cdot \sum_{i=1}^{k} z_i \cdot s_i}$$

Table 2: Objectivity of interpretation of errors by calculation of Cohen’s kappa-Coeffizient;
k = number of row/column; n = overall frequency; zi = sum of rows; si = sum of columns; di = frequency in diagonal

3.2 Quantitative analysis

We analyzed following parameters: 1) the maximal complexity (MC) which is the number of all connections the student created; 2) the actual complexity (AC), is the complexity of the concept map after all incorrect relations were deleted; 3) the corrected actual complexity (CAC), is the AC after all relations, that are incorrect with regard to the content but not in respect of technique were deleted; 4) the number of all mistakes; 5) the number of subnets are nets without connection to each other within the concept map (fig. 1(B)). In this study a perfect concept map has only one net.

3.3 Qualitative analysis - Comparison between the subject matters

We considered six error types made while constructing the concept maps. In our opinion there are three reasons why students made errors: they did not understand the method of concept mapping (1), the content (2), or both

(3) (Table 3). We followed the classification of Schmucker (2007). We differed in the estimate of the reason of error F5 *(SG3)*. In our opinion this is not a problem of the method, but of the students' knowledge.

The pre-test attests previous knowledge about subject (A) (mean score 58%) but hardly any about subject (B) (mean score 41%). Students had already hands-on experience with subject (A), but not with subject (B) which was abstract including many Latin terms. Due to these findings we distinguish between the subjects as (A) easy and (B) complex. To evaluate under which circumstances concept mapping may provide a useful method to get a general idea of a topic we compared the concept maps about the two subject matters. Furthermore, we analysed whether concept mapping can match with conventional knowledge tests, we correlated both the actual complexity AC and the corrected actual complexity CAC of the concept maps with knowledge scores.

error types	***possible reasons for errors***	***example***
F1: *right linking phrase – wrong direction of arrow (S5)*	*method not apprehended*	Frog ← breaths with — lung
F2: *right linking phrase – no direction of arrow (S4)*		Frog — breaths with → lung
F3: *wrong linking phrase – direction of arrow indicated (S6)*	*content not apprehended*	Frog — breaths with → gills
F5: *wrong linking phrase – no direction of arrow (S3)*		Frog — breaths with — gills
F4: *no linking phrase – direction of arrow indicated (S1)*	*method and content not apprehended*	Frog — .. → lung
F6: *no linking phrase – no direction of arrow (S2)*		Frog — .. — lung

Table 3: Error types and possible reasons for errors *(S = definition of Schmucker2007)*

3.4 Correlation between Concept Maps and knowledge post-test

In order to check whether concept maps represent students' content knowledge, we correlated the complexity of the concept maps with students' knowledge scores of the post-test. In doing so we distinguished the actual complexity AC without errors in respect of both content and method and the corrected actual complexity CAC without mistakes in respect of content. The correlation was tested by a bivariate correlation with Spearman's Rho and two-tailed significance.

4 Results

4.1 Analysis of objectivity

The analysis of objectivity according to Zöfel (2002) revealed for both analyzers a coincidence of 82% for subject (A) "Polliwog to Frog" and 70% for the subject (B) "Ecosystem Lake", respectively. The coincidence of the 1st and 2nd analysis of the same analyzer is 83 % (subject (A)) and 97% (subject (B)).

4.2 Quantitative analysis

Due to our data' non-normal distribution we used non-parametric analysis. 58.6% of our concept maps about subject (A) embodied less than 6 mistakes, the median is 5 mistakes. Only 27% of the concept maps about subject (B) contain just small mistakes. In 62.7% of them about 6 to 25 mistakes were found. The median is 8 mistakes (Figure 2). The median of the actual complexity AC of the concept maps about subject (A) is 13, about subject (B) 11 (Figure 3). The corrected actual complexity CAC is higher with a median of 14 about subject (A) and 14.5 about subject (2) (Figure 7). The median of subnets per concept map is 5 about subject (A) and enormous 13 about subject (B) (Figure 5).

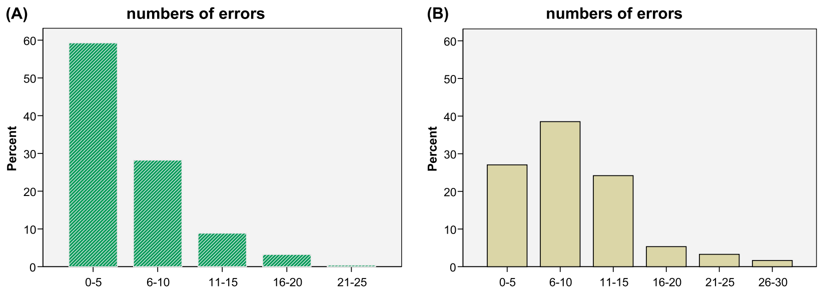

Figure 2. Number of errors per cmap (A) "Polliwog to Frog" (B) "Ecosystem Lake"

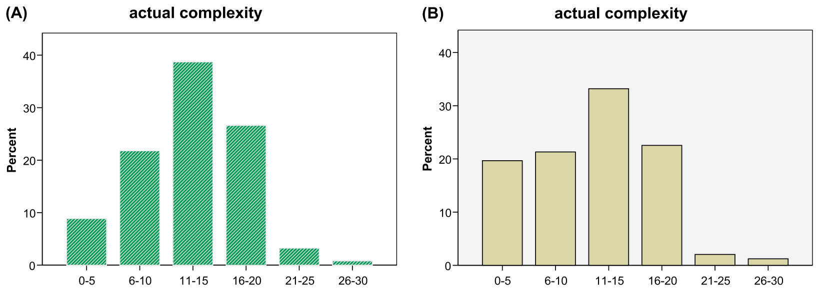

Figure 3. Actual complexity (A) "Polliwog to Frog" (B) "Ecosystem Lake"

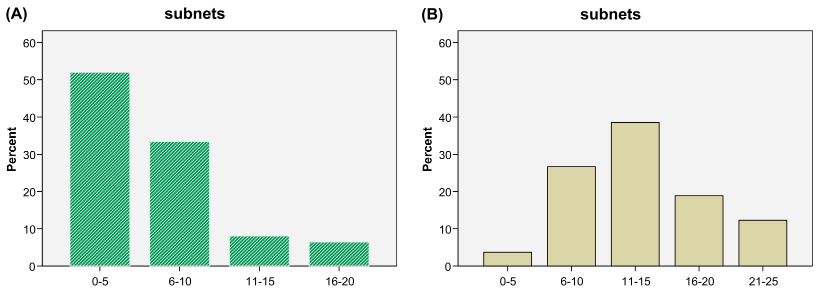

Figure 4. Numbers of subnets per cmap (A) "Polliwog to Frog" (B) "Ecosystem Lake"

4.3 Qualitative analysis - Comparison between the subject matters

In both subjects, it matters the percentage of mistakes F1, F2 and F4 which is shown to be equivalent (Figure 5). F1 and F2 are technical errors just as F4: the connection was mislabelled without any direction. There are substantial quality differences between the two subject matters with regard to the content errors and the content & method errors (Figure 5). The easier, less complicate subject (A) contained more than 51% mistakes F3, doubtless with respect to the content. But the more difficult and complex subject matter (B) produced only 29% of F3 mistakes. Instead of F3 errors F5 and F6 increased substantially in percentage.

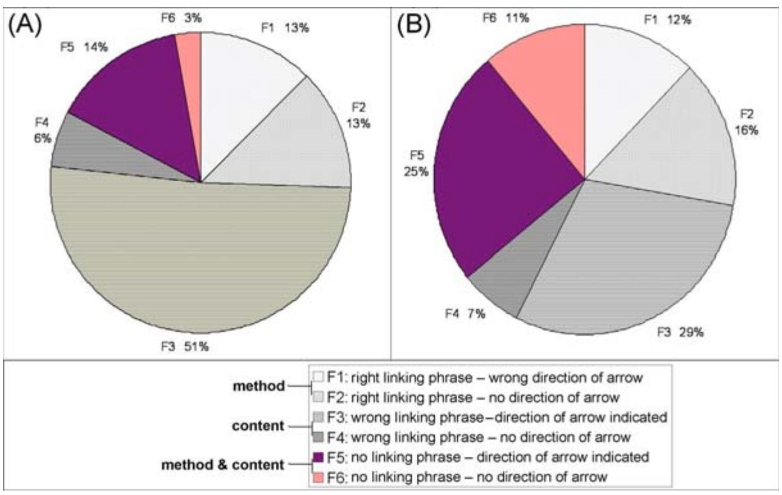

Figure 5. Distribution in percentage of error types (A) "Polliwog to Frog" (B) "Ecosystem Lake"

4.4 Correlation between Concept Maps and knowledge post-test

Cognitive knowledge tested by pre- and post-tests increased in both subject matters (tab.4 p=0.000). Figure 6 shows the CAC in comparison with AC for both subjects. The number of concept maps with high complexity increases especially for subject (B). The correlation AC of concept maps and knowledge tests are highly significant. The CAC without deletion of technical errors correlates even better (Table 5). However, the correlations with the post-tests are weak with coefficients about 0.2 (tab. 5).

Subject Matter	*Test*	*sum score*	*SD*	*Wilcoxon*	
				Z	*asymp. Sig. (2-tailed)*
(A) Polliwog to Frog	prae-test	5.9	1.91	-12.662	0.000
	post-test	8.5	1.32		
(B) Ecosystem Lake	prae-test	2.9	1.13	-11.579	0.000
	post-test	4.4	1.36		

Table 4: Sum scores of pre-test and post-test of subject (A) and (B) and Wilcoxon test

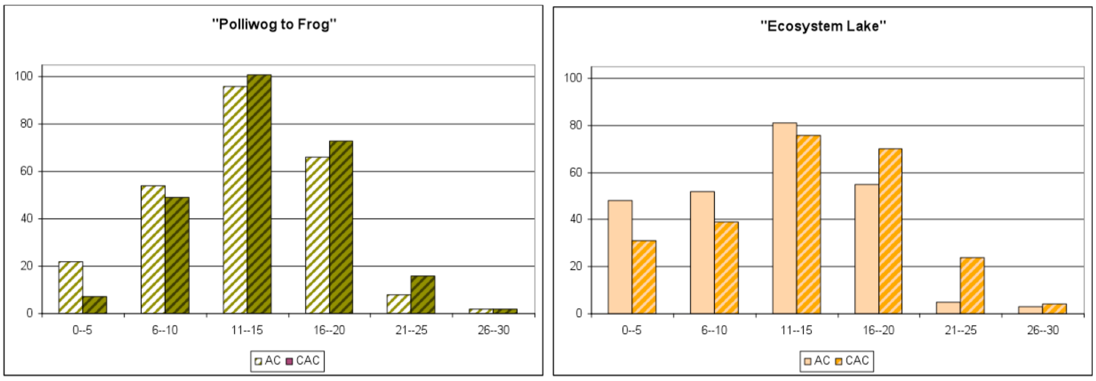

Figure 6. Actual Complexity AC and Corrected Actual Complexity CAC for (A) "Polliwog to Frog" and (B) "Ecosystem Lake"

Subject Matter	*Complexity*	*Correlation Coefficient*	*Sig. (2-tailed)*
(A) Polliwog to Frog	actual complexity AC	,195	0.002
	corrected actual complexity CAC	,208	0.001
(B) Ecosystem Lake	actual complexity AC	,271	0.000
	corrected actual complexity CAC	,297	0.000

Table 5: Spearman's Rho of knowledge post-test and AC / CAC of concept maps

5 Discussion

5.1 Analysis of objectivity

Objectivity of analysis of the concept maps is given in both subject matters according to Zöfel (2002). In Subject (B) there is a relatively low coincidence of 70% between the two correctors with the high coincidence of 97% of the self-testing. This indicates the complexity of the subject (B) with a high firmness of the corrector.

5.2 Quantitative analysis

To sum up, the more difficult the subject matter, the more mistakes and thereby the more subnets and low AC were produced in the concept map. The easier the subject, the fewer mistakes and subnets and higher AC were produced. The CAC indicates an overestimation of errors or rather an underestimation of the student's illustrated knowledge.

5.3 Qualitative analysis

Because of the lack of monitoring feedback about the errors in the 1st concept map (A) students could not eliminate these technical mistakes. Thus students need a second corrective introduction into the method of concept mapping, but as it seems to come naturally to them good concept maps are not necessarily an effect of more training.

Evidence suggests that the reduction of F3 errors in concept maps about subject (B) in comparison with subject (A) is because of the increase of F5. We cannot exclude that all students had enough time to finish their concept map, but the majority had. We suggest students may have been overburdened with the complexity of subject (B) and they may have tried to jot vague retention down. As this knowledge was weak students were not able to verbalize it in form of correct labelling of the relations. Cognitive overload is also possible as subject (B) was much more complicate including Latin terms and the number of items high (Scharfenberg, Bogner, Klautke 2007; Nückles 2004).

5.4 Correlation between Concept Maps and knowledge post-test

Concept maps could represent students' knowledge; however under the conditions of the present study concept maps could not be a substitution for knowledge tests. Difficult subject matters appear to cause an overestimation of errors. The correlation AC of concept maps and knowledge tests are highly significant, but weak. This is consistent with Novak, Gowin and Johansen (1983). A concept map reflects its draughtsman's knowledge. However, too many factors exist aside from the subject knowledge such as someone's ability in verbalisation. This is supported by the findings with CAC, which correlates better than the AC (Table 4). The CAC without deletion of technical errors suggests representing cognitive knowledge of the subject whereas the AC represents the ability of concept mapping, too.

6 Summary

Young students are able to handle concept mapping very well although the technique is absolutely new to them. This is true if the subject matter is easy. On the other hand, students failed to do so with a complicate subject matter. This is completely in line with Slotte & Lonka (1999).

Student made similar percentage of mistakes F1, F2 and F4 in both concept maps. Due to the lack of feedback after the construction of their 1st concept map, students could not eliminate these mistakes. This needs a 2nd explanation by the teacher. More training is not necessary as concept mapping seems to come naturally to children.

In spite of the successful practice with the first concept map (subject (A)) which achieved good results, students failed with the second subject (B), mainly caused by an increase in number of mistake F5 and F6 with simultaneous decrease in percentage of mistake F3. As the majority of the students could finish the concept map in time we suppose these mistakes reveal specific knowledge gaps. Students may have been overburdened with the complex subject and they may have tried to jot vague retention down. As this knowledge was weak students might not been able to verbalize it in form of correct labelling of the connections. Cognitive overload is also possible as subject (B) was much more complicate and the number of items high (Scharfenberg, Bogner, Klautke 2007; Nückles 2004).

We found a significant correlation between knowledge test scores of students and the complexity of their constructed concept maps. For the AC we did not different between methodical error and in respect of content. This could have caused an underestimation of the mapped knowledge. The CAC ignores methodical mistakes. The correlation of CAC with the knowledge test scores is higher then with the AC, but both are weak. In spite of the high variance a concept map could provide an indication of the student knowledge. So concept mapping application could be an adequate consolidation phase revealing specific knowledge gaps additionally. This could give teachers a guideline for the further schedule close to the students' needs.

Evaluation Programme

Mannheimer Netzwerk Elaborations Technik MaNet Version 1.6.1.
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