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Enriching traditional biology lectures– digital concept maps and their influence on achievement and motivation

Steffen Schaal

Faculty of Human Sciences an Education, University of Bamberg, 96047, Germany

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Abstract

Higher education deals with complex knowledge and university teaching should focus on conceptual understanding. Adequate knowledge structures are essential and active knowledge construction should be supported for meaningful learning. But traditional lectures mostly are structured by slides which may misleadingly cause linear representations of knowledge. In this study, a framework for digital concept maps was developed to complement lectures in human biology. The course was aimed at student science teachers at the undergraduate level. The work is based on theoretical research on computer-supported learning, on knowledge structures perspectives within learning environments as well as on self-determination theory. Each session was supplemented by a digital, multimedia-enriched concept map. After each single lecture, students had free access to the concept maps to reinforce the latest topics. The objective of the study was to examine if the use of complementary concept maps (i) influences achievement and (ii) if motivational variables influence the use of the concept maps. In both cases, influences of computer-user self-efficacy were expected (iii). The students' (N = 171) concept map use was logged, achievement was tested and motivational variables were surveyed (e.g. interest/ enjoyment, perceived competence, effort/ importance, value/usefulness). The logfile-data allowed distinguishing learners according to their concept map use. Results reveal the benefit of additional concept maps for achievement, positive motivational aspects and computer-user self-efficacy as mediating factors showed some influence. The emphasize of further research should be on students' active engagement in structuring their individual learning by constructing concept maps themselves, especially in science education courses.

Keywords: Science education; pre-service teacher education; digital concept maps; computer-assisted learning; concept and content knowledge.

1. INTRODUCTION

Learning at university level deals with complex and divers topics. Promoting domain specific problem solving is based on meaningful, conceptual understanding of central ideas of a topic (Sigler & Saam, 2006). Cognitive psychology introduces several processes by which schema, propositions, concepts or specific prototypes are formed (Anderson, 2004). Moderate constructivist approaches to individual learning are widely accepted in the scientific community, especially in science education (Mintzes, Wandersee & Novak, 2005), and implications of active knowledge construction are well investigated (for an overview see Novak, 2010).

In contrast, students' prior knowledge differs widely at the beginning of the tertiary educational level, which reveals difficulties in connecting appropriately scientific concepts to existing knowledge (Buntting, Coll & Campbell, 2004). Furthermore, students entering university use mostly learning strategies which they experienced to work well in school (Merriam & Caffarella, 1999). But these learning strategies are often based on behaviorist learning paradigms in the context of a final examination and are often characterized by inadequate linear knowledge representation (Kinchin, 2009). This false linearity of knowledge structures might even be emphasized by using Powerpoint slides in lectures (Kinchin, Chadha & Kokotailo, 2008) and thus students miss to reflect the structural aspects of their individual achievement.

Therefore, Kinchin (2009) supposes to apply concept mapping as a means to develop a constructivist student-engaged pedagogy. Concept maps visualize a learners expertise, moving from a novice linear structure to an expert's network of a knowledge domain. Daley (2002), for instance, describes the use of concept maps to promote adult learners' insight into constructivist learning approaches and thus, their understanding of knowledge construction as an active linking of ideas or concepts into reliable and stable networks and schemes. Concept mapping techniques have been described to advance academic teaching in general (Ledermann & Latz, 1995; Kinchin, Hay & Adams, 2000; Sherborne, 2009, Kinchin, 2009), computer-based concept mapping in teacher education programs has shown multiple positive effects (Ferry, Hedberg & Harper, 1997; Countinho & Bottentuit, 2008). Buntting, Coll and Campbell (2006) focused the use of concept maps in introductory tertiary biology classes and their results point towards students' high acceptance of the method. In this case, students perceived concept mapping to be enjoyable and useful to link different concepts for meaningful learning.

Nevertheless learners are not familiar with the technique of concept mapping when they enter university, and thus, it has to be trained. Early work on mapping techniques showed evidence, that cognitive load exceeds individual resources if the learner is not used to the method (Holley & Dansereau, 1984). Even if adult students have used concept mapping successfully, one third of them stops mapping if it is not explicitly required (Daley, 2002). Kinchin (2001) also pointed towards a bias between an evidence-based potential of concept mapping to support and enhance students' learning and the actual use in secondary schools.

In general, user experience and satisfaction with a new technique are important criteria in the personal overall evaluation of that technique (Vennix & Gubbels, 1992). Allen and Tanner (2003) exemplify the problems while using concept maps for the first time. They point out the necessity to introduce the method carefully to avoid overstraining demand and thus a learners' refusal. Furthermore, according to the self-determination theory of Deci and Ryan (Ryan & Deci, 2008; Niemec, Ryan & Deci, 2009), the perceived competence while working with this technique or its perceived usefulness are important variables to apply it in future tasks. Concept maps help the learners to organize the knowledge, to elaborate or to repeat existing concepts while actively working on a topic (Kinchin, Hay & Adams, 2000). As a learners' access to individual knowledge is facilitated by the use of concept maps, psychological needs for self-determined learning like for instance the need for competence or the need for autonomy could be positively influenced.

In addition, self-efficacy moderates the application of a meta-cognitive technique like concept mapping. Self-efficacy can be defined as one's appraisal of his/her capabilities to organize and execute courses of action required to attain types of performances (Bandura, 1986, p. 391). In the context of this study, self-efficacy affects effort and persistence while using a specific technique or supporting material and people who believe they are capable are likely to participate. Recent self-efficacy is for example based on individuals' performances in a task as well on their observational experiences (Pintrich & Schunk, 2002). Gurlitt & Renkl (2009) highlighted the role of concept maps in prior knowledge activation for successful learning. They consider self-efficacy as an important variable for future learning. Especially when computer-supported methods are applied to foster learning, the specific computer user self-efficacy influences the success of a learning environment (Cassidy & Eachus, 2002) and, as consequence, also the use of a specific technique like the concept maps.

The purpose of this study was to develop and to evaluate concept maps as supportive material for a traditional lecture in human biology for pre-service teacher education within large auditoriums. These supportive concept maps should be seen as low-threshold access to concept mapping during the further university education and, in the long run, to implement them in secondary schools.

2. DIGITAL CONCEPT MAPS IN SCIENCE TEACHER EDUCATION

According to Novak (1998) a concept map is “a schematic device for representing a set of concept meanings embedded in a framework of propositions” (p. 15). Within a Novakian concept map, concepts and propositions are hierarchically structured. The most general ideas or concepts of a topic are represented at a higher level, whilst the more specific details are arranged below (Novak & Cañas, 2008). In literature, the potential applications of concept maps are in planning teaching and in curriculum development or as assessment tools (Schaal, Bogner & Girwidz, 2010) and as tools to support learning (Lawless, Smee & O'Shea, 1998). Under a constructivist learning paradigm the construction of concept maps is an active process of personal meaning-making (Åhlberg, 2004, Novak, 1998). It helps students to organize and to structure their knowledge and thus affects their intellectual performance in general (Bransford, Brown & Cocking, 1999).

In the domain of biology, concept mapping offers broad and successful implementation in classrooms (Kinchin, 2000). As ”biology is […] difficult to learn because it consists of […] unfamiliar concepts involving complex relations” (Schmid & Telaro, 1990, p. 78), concept maps provide a coherent structure of the topic and thus expatiate on essential links between central concepts (Martin, 1994). Especially in complementary combination with traditional, objectivistic teaching approaches, concept maps might give new impetus to enrich students learning experiences and to develop teacher reflection “by encouraging them to think beyond linear sequences” (Kinchin, 2006).

In pre-service science teacher education concept mapping fosters science understanding and may decrease anxiety towards learning and teaching science (Czerniak & Haney, 1998). But not only actively constructing concept maps creating concepts and relations promotes the learners' achievement, similar learning success in reproduction can be achieved working with a pre-structured expert's concept map (Jüngst & Bernd, 1999). Hence, a concept map can serve as advance organizer for prior knowledge activation (Gurlitt & Rekl, 2009) or as summary tool, both representing coherently a complex domain's structure.

In combination with the potential of Kozma's (2003) reflections on multiple representations and their interpretation for deeper understanding in science education, digital concept maps have the potential to foster successful learning in the domain of science education. Rojer and Rojer (2004) as well as Yin and colleagues (2004) reported of general advantages of digital concept mapping compared to paper-and-pencil procedures.

Dansereau (2005) differentiates three types of digital concept maps:

- *Information maps*: expert generated maps for presentation of information, orientation and navigation,
- *guided maps*: self-constructed novices' *maps* with adequate support, with e.g. pre-defined nodes or concepts,
- *freestyle maps*: user generated maps without constraints.

Neumann, Graeber & Tergan (2005) highlight the potential of *information maps* within a learning scenario of resource-based learning. They report positive effects in knowledge identification and interpretation using a digital structuring and presentation tool.

A promising body of resent research introduces the potential of digital media to advance concept mapping, for instance, allowing to collaborate in concept mapping and to share knowledge independent from time and location (Novak & Cañas, 2004). Digital concept maps provide access to complex and ill-structured knowledge domains and thus they are powerful aids to represent or to organize knowledge adequately (Alpert & Gruenenberg, 2000, Tergan, 2005). Digital concept maps do no longer consist of node-link-node diagrams like paper-and-pencil formats. In fact, digital concept maps allow to link further sub-maps, further textual and pictorial information or other digital ressources like animations, simulations or videos (*cf.* Alpert, 2005, 2006, Tergan, Keller & Burkhard, 2006). Thus, these further materials allow an active knowledge-construction adding in educational settings for example aspects of problem-solving tasks and of situated learning.

Sophisticated theoretical concepts for the use of digital media in science education exist and their potential for meaningful, conceptual learning is undoubted. For instance, Girwidz and colleagues (2006) have described several guidelines on the basis of psychological findings. They assume *multicoding*, *multimodality* and *interactivity* as special features of multimedia. Especially they foster the promotion of cognitive flexibility, the construction of mental models, the implementation of situated learning as well as the linking of different fields of knowledge while using multimedia in science education. In this present study, CmapTools software was used (http//:cmap.ihmc.us) to create web-compatible concept maps which offer access to different material described above. Within teacher training, Coutinho and Bottentuit (2008) reported successful implementations of Cmap-tools in web-based post-graduate training.

As conclusion for the present study, pre-defined *information maps* serve as a first access to the "world of concept mapping" in teacher education, providing relevant *conceptual* knowledge about human biology in combination with digital resources to foster simultaneously *content* knowledge construction. Pre-defined concept maps have been identified to activate prior knowledge better than a less-structured procedure when elaboration strategies are important for achievement (Gurlitt & Renkl, 2009). Furthermore, Gurlitt and Renkl (2008) highlight the benefit of more pre-defined concept maps in science education for lower-experienced learners compared to less pre-defined ones.

The Aim of the Study

The main goal of the study is to investigate the cognitive effect of using pre-defined summary information maps as supportive materials in pre-service teacher education for an elementary lecture in human biology. The first hypothesis is:

(i) that the use of supportive concept maps improves the achievement of the relevant concepts of human biology.

Furthermore, according to the theory of self-determination, predictors for intrinsic motivation e.g. interest and enjoyment while working with the given concept maps, perceived competence and the perception of the method's usefulness affect learners' achievement and the access to the material. Thus, the second and third hypotheses are:

(ii) The frequency of concept map use is correlated with specific interest and enjoyment, competence and usefulness perception. Furthermore, the overall motivational disposition influences the achievement as well as the use of concept map.

(iii) The computer-related self-efficacy affects the frequency of concept map use directly as a moderating variable and indirectly in interaction with the motivational aspects.

3. METHODS

3.1. Sample

In total, N = 171 (of 249 lecture participants) student teachers for primary and secondary schools completed the whole test schedule and were considered in data analyses, their average study semester was 1.6±1.4 (mean±SD). Participation was voluntary, unpaid and anonymous, students' written consent was obtained.

3.2. Procedure

This study was realized under ecological condition in regular lectures in human anatomy and physiology for pre-service teacher students at the University of Education in Ludwigsburg during the winter and spring semester of 2008/2009. The lectures in human biology are obligatory for each teacher student and thus, the auditorium consists of more than one hundred students per session, which renders practical work impossible. Fourteen weekly lectures in traditional formats about the relevant human organic systems (*e.g.* human respiratory and circulatory system, morphology and physiology of senses, human anatomy) were given by the same lecturer. Each session lasted 90 minutes. At the end of semester students were rated in a final exam.

Accompanying each reading student had online-access to the presentation slides and as well to a digital concept map of the specific topic (*e.g.* chemical senses), providing links to further web-resources, images and diagrams, videos or animations. The concept maps were constructed according to the guidelines of Novak and Cañas (2008). Students' access to the digital concept maps was logged.

During the last session, students completed a *Computer User Self-Efficacy Scale (CUSE)* and the relevant items of the *Intrinsic Motivation Inventory (IMI)*. Finally, one week after the last session, a 30 minutes multiple-choice assessment with 14 items (each consisting of four declarations with three distractors and a correct solution) had to be completed. Along with the first online resources learners had access to examples of the exam test items that was logged too, and was used as an indicator of prior knowledge.

3.3. Instruments

The multiple choice achievement test consisted of one item each for the fourteen topics of the sessions. Each item consisted of four plausible (but only one correct) arguments from which the students were to choose according to the instructions. Furthermore, an anatomic drawing of the digestive system had to be labeled and each part had to be assigned to a specific function within the process of digestion. A total of thirty-six points could be scored. After the first session, students had online-access to three exemplary items of the test and the results were logged to reveal learners' potential prior-knowledge differences.

Motivational variables were measured with a German version of the Intrinsic Motivation Inventory (Schaal, 2006). The IMI is a multidimensional measurement device intended to assess participants' subjective experience related to a target activity (Plant and Ryan, 1985; Ryan et al., 1990). Three dimensions of the scale were used: interest/enjoyment (eg. 'I thought using the digital concept maps was quite enjoyable'), perceived competence (eg. 'I am satisfied with my performance at learning with the concept maps') and value/ usefulness (eg. 'I believe doing this activity could be beneficial to me') of the concept mapping technique. Each item was rated on a five point Likert-scale (1 for completely true and 5 for completely false). Reliability of the three dimensions was between 0.89, 0.90 and 0.92.

Computer User Self-Efficacy Scale is mainly used to identify students, who perceive difficulties in computer-supported learning environments (Cassidy & Eachus, 2002). CUSE consists of 30 items, in this study a German translation was utilized (Spannagel, 2007). Each item was rated on a six point Likert-scale (1 for completely false and 6 for completely true).

4. FINDINGS

Students' concept map use differed widely from non-usage to approximately 100 accesses with an average of $M = 24.5 \pm 15.8$ accesses. The concept map use did not differ significantly from a normal distribution (Kolmog.-Smirn. $Z = .935$, $p > 0.3$).

Hypothesis (i) concerning the influence of the *concept map use* on the achievement was determined using a GLM (Generalized linear model) with the achievement score as dependent variable, the average of all motivational variables as factor and the *CUSE* as as well as the prior-knowledge as covariates, only main effects were respected. Prior-knowledge had no relevant influence on the scores of the achievement test in a first model ($F = 0.081$, $p = 0.65$), and thus it was eliminated for the final model. In general, all variables didn't differ from a normal distribution and fulfilled the prerequisites for application of the relevant statistical procedures.

The GLM shows, that concept map use as well as the sum of motivational variables significantly influence the achievement, both indicating strong effect sizes (Table 1). Hence the first hypothesis (i) can be confirmed.

Table 1 Generalized linear model (GLM) with achievement score as dependent variable, concept map use and motivation as factor and CUSE as covariate. Corrected $R^2 = 0.44$ (* p < ,05/ ** p < ,01/ ns = not significant)

N = 171	**Sum of Squares (type III)**	***df***	**Mean Square**	***F***	**Significance**	**Partial Eta-square**
Corrected model	2655,34	74	35,89	2,257	,002**	,791
Cmap use	686,07	24	28,59	1,798	,045*	,495
Motivation	1373,43	36	38,15	2,400	,003**	,663
CUSE	9,975	1	9,98	0,627	,433^{ns}	,014

The applied model seems to fit quite well as indicates a coefficient of determination R^2= 0.44. Nevertheless some "hidden" variables may influence the results and further uncontrolled parameters seem to be important for the achievement. These might be, for instance, more holistic aspects of the prior knowledge, the general achievement level in science education, personal learning styles or beliefs about learning in general as well as further personal psychological traits.

Hypothesis (ii) expecting the correlation of the motivational variables *perceived competency* and *interest/ enjoyment* while using concept maps as well as the *perceived usefulness* of the technique was tested first (Table2). All three variables showed highly significant correlations to the frequency of digital concept maps use, which confirms the first assumption of this hypothesis.

Table 2 Correlations of motivational variables and the concept map use frequency (*** p < ,001)

N = 171		**Interest/ enjoyment**	**Competency**	**Usefulness**
Cmap	Correlation (Pearson)	0,375***	0,291**	0,399***
frequency	Sig. (2-s.)	0,000	0,001	0,000

The second assumption of hypothesis (ii) and hypothesis (iii) were tested using GLM with the concept map use frequency as dependent variable, the average of all motivational variables as factor and the *CUSE* as covariate. Main effects and the interaction-effect of *CUSE* and the motivational variables were respected in the model. The results reveal a significant influence of the motivational variable, while a direct influence of the computer-related self-efficacy should be neglected (Table 3). But the interaction between *CUSE* and the motivational aspects contributes a highly significant influence to the frequency of concept map use. Therefore, hypothesis (iii) concerning the influence of self-efficacy could only partially be confirmed. The results reveal different achievement levels for *low-* and *high-intensity concept map users* and concept map use might influence the learning outcome within the domain of human biology.

As expected motivational variables influence the concept map use while it is not affected by lower *CUSE* values, indicating learners' computer-related difficulties in using digital concept maps. This field study was conducted under 'ecological', non-experimental conditions, some implications for entry-level lectures in human biology and for further research could be derived.

Table 3 Generalized linear model (GLM): concept map use frequency as dependent variable, motivation as factor, CUSE as covariate. Corrrected R^2 = 0.86 (* p < ,05/ ** p < ,01/ *** p < ,001/ ns = not significant)

N = 171	**Sum of Squares (type III)**	***df***	**Mean Square**	***F***	**Significance**	**Partial Eta-square**
Corrected model	33000,95	71	464,80	14,02	,000***	,955
Motivation	5901,04	21	281,00	8,48	,000***	,791
CUSE	50,78	1	50,78	1,53	$,222^{ns}$	,032
Motivation*_CUSE_	5240,75	21	249,56	7,53	,000***	,771

5. CONCLUSION

A body of evidence fosters the benefit of concept mapping to activate prior knowledge, to create sustaining knowledge structures and to help learners to cross-link different aspects of a knowledge domain. The specific potential of digital concept maps is to promote the construction of *conceptual* and *content* knowledge as well as to offer knowledge resources in an adequate visual representation (Tergan, 2005). The findings of the study presented in this paper are in line with this assumption and indicate, that digital concept maps help students to get an adequate overview of the domain's knowledge structure as well as to integrate further information resources into this network of concepts and relations. Digital concept maps are a fruitful support within formal university education, if students are aware of its usefulness.

But as university students at the entry level are not used to the method of concept mapping, they should be supported step-by-step towards a constructive use of this method during their university education. Dansereau (2005) suggested to start concept mapping in a guided mode within instructional settings like the lecture in human biology described in this paper. Afterwards, if students are once used to work with pre-defined information maps, they will be more confident of creating concept maps on their own to support their academic learning. And the impact of self-constructed concept maps on learning has been often described in different scientific disciplines (Novak, 2010; Tzeng, 2009; Chularut & DeBaker, 2004). This recent study indicates, that a learning process in traditional lectures could be improved just by using another kind of external knowledge representation, which fosters the explicit visualisation of a complex biological topic's structure. Thus, the recent study adds some further evidence to the insertion of the concept map technique in a more assimilative way which means, that just using an information map can improve academic learning. This is in line with the findings of Jüngst and Bernd (1999) as well as with those of Gurlitt and Renkl (2009). The latter explain advantages of pre-defined concept maps for low-expertise learners in the domain of text comprehension by the explicit presentation of coherent structures to facilitate the integration of new knowledge into existing knowledge as a sort of advance organizer (Ausubel, 1968). Additionally, the findings presented in this paper are in line with earlier research results. Schaal and Bogner (2005) used digital representation of a knowledge structure within an interdisciplinary hypermedia learning environment about hibernation. They found that learners who often used this domain's visual overview for navigation felt more competent and perceived the topic to be more useful and relevant for their everyday life.

In a next step, concept mapping techniques should be elaborated to a more constructive use by visualizing and generating conceptual knowledge within individuals' own concept maps during a learning process. But DiCerbo (2007) described a potential bias between the knowledge structures intended by the teacher and the actual structures within the concept maps constructed by the students. She suggests initializing learners' reflections about their recent conceptualizations by using methods promoting conceptual change. This could be done within university courses in small groups and practical laboratory work to get further insight into human anatomy and physiology.

As consequence for the successful integration of concept mapping in university education, lecturers should not only use this technique to support knowledge organization, additionally it is important to give the learners the experience that concept mapping works for their individual achievement. This perception of a method's usefulness is important for its further application (Buntting et al., 2006).

The final goal in the context of teacher education at universities could be the implementation of digital concept mapping to adhere the conceptual knowledge of the different scientific disciplines and to enrich it with further information resources as a complete portfolio of academic achievement. Especially a science teacher might profit from approaches to meaningful learning, which he/she hopefully will implement into his/her own teaching practice.

The validity of the results is adequate for a fieldwork, but the data suggest further confounding variables for the achievement of human biology knowledge. Another critical aspect of the findings presented in this study is a potential bias between learners' prerequisites, the use of the digital concept maps and the achievement. The data leave an uncertainty, because the results cannot clearly be appointed to the methods' use or to learners' individual differences which lead to advantages for those learners who more often used the concept maps. Though within the statistical procedures prior-knowledge was respected as confounding covariate, personal learning styles or general cognitive abilities were not taken into account. It might be possible, for instance, that the more capable learners more often used the digital concept maps. Thus, for further research, prior knowledge and learning styles of pre-service teachers should be controlled and integrated into a more sophisticated, far-ranging model to quantify the effective influence of additional learning materials for achievement. Furthermore, a longitudinal research design should reveal if the stepwise implementation of concept mapping into science teacher education at universities could promote teacher students' attitudes towards this visualization and learning technique and consequently, if it also influences its transfer into everyday science education classrooms.

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