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TESTING ACHIEVEMENT WITH CONCEPT MAPPING IN SCHOOL PHYSICS

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Abstract. This article describes the use of concept mapping for achievement testing in school physics. It is based on two empirical studies with 9 and 10 grade students. In the first study the students' knowledge was tested with concept mapping before and after learning sequence about the topic "Energy supply in a dynamic system of different power stations". Two different teaching methods ("traditional" and STS) were compared with a control group design. The results confirm that concept mapping is a suitable method for testing students' declarative knowledge and that the STS method is appropriate method for physics concepts. In the second study we researched relations between students' knowledge and competences to act. The topic in this study was "Energy consumption at home". We couldn't find any proof that knowledge influences acting directly, but these students who had more knowledge, acted in some aspects more relevant.

1 Introduction

This article describes the use of concept mapping for achievement testing in school physics. It is based on two empirical studies with 9 and 10 grade students in Germany and Estonia. Both studies are part of a research project, which deals with the connection between science teaching and action.

In the first study the students' knowledge was tested with concept mapping before and after learning sequence about the topic "Energy supply in a dynamic system of different power stations". Two different teaching methods ("traditional" and STS) were compared with a control group design. In the second study we researched relations between students' knowledge and competences to act. The topic in this study was "Energy consumption at home."

2 Method used in both studies: concept mapping

The constructs activated in long-term memory are called concepts in cognitive psychology. These concepts represent the information depending on our experience and our relations to this information. The concepts are connected with each other. The concepts activated in our memory construct a data bank that helps a person make decisions and act. In such kind of formulations the word "concept" takes the first place (Hoffmann, 1994). Still the meaning of a concept in cognitive psychology is not identical with the meaning of a concept in education.

According to Arbinger (1991) there are three kinds of knowledge presentation: declarative knowledge, procedural knowledge and analogical knowledge. Declarative knowledge is recorded as a proposition. A sentence consists of two related concepts. Every sentence is meaningful; it can be evaluated and presented by its structure. Declarative knowledge can be divided into episodic and semantic knowledge. Episodic knowledge involves personal experience; semantic knowledge is more general and is a sum of single occasions of experience.

According to Tergan (1986) knowledge is organized and structured. Like Arbinger, Tergan differentiates between three kinds of knowledge presentation, one of them being semantic spatial model. Semantic spatial models represent declarative knowledge. Knowledge is sorted by similarity of the concepts (psychometric model), is presented by sentences as a network structure (network model) or is visualized conceptually (conceptual model).

Concept mapping is a graphic technique for representing ideas, helping to think, solving a problem, planning a strategy or developing a process. Concept mapping means connecting different concepts of the subject and constructing relations by compiling the map. The concept mapping method is based on the theory of meaningful learning (Ausubel, 1963) and on the assumption that knowledge is saved in the human brain propositionally and the generated concept maps just represent this propositional knowledge saved in the brain (Atkinson, Shiffrin 1968, Norman, Rumelhart 1978). The method was introduced in didactics by the American scientist Novak (1990) in the 1960s. Later on analogous methods have been developed by several research groups (see Scheele & Groeben 1984 or White, Gunstone 1992). Much success has been achieved by the application of concept mapping in the teaching process to integrate new concepts into the existing system of knowledge (Novak 1990).

“Concept mapping is a process of meaning-making. It implies taking a list of concepts – a concept being a perceived regularity in events or objects, or records of events or objects, designated by a label, – and organizing it in a graphical representation where pairs of concepts and linking phrases form propositions. Hence, key to the construction of a concept map is the set of concepts on which it is based.” (Cañas et. al. 2003).

Today concept mapping is widely and successfully applied in many different fields of education, e.g. concept mapping is widely used in science education (Behrendt et. al. 2000; Fischer et.al. 2001; Reiska 1999, 2005).

Reiska (2005) describes some advantages of using concept mapping in education:

- Possibility to use concept mapping in every phase of teaching process (e.g. at the beginning of lesson for introducing a new concept or at the end of lesson to assure the learned concepts);
- Independence of age (concept mapping can be used by children in kindergarten but also by adult students in the university)
- The constructing of maps helps students to reflect on they own knowledge;
- Concept mapping helps students to concentrate themselves in the process of group work;
- Concept maps give teachers information about students` knowledge;
- Concept mapping can be used for planning the lessons.

3 Using concept mapping as an assessment tool

When the method of concept mapping is used in lessons or in research, a significant component of the application is the evaluation of concept maps. Reiska (2001) describes four different types of evaluation. They range from intuitive impressions only to computer-aided quantitative evaluation. In addition, the possible stages are listed according to the type of evaluation and computer application:

1. Intuitive evaluation

Intuitive evaluation is suitable for giving advice on learning with the aid of concept maps. The advisor or researcher is able to view the maps of the subjects and, on the basis of intuitive impressions (size, structure and correctness of individual propositions), evaluate the range of the subject’s knowledge. An intuitive evaluation can only be performed with small, clear concept maps. This kind of evaluation is not very suitable for comparative studies because the results are only intuitive and depend to a large extent on the respective interviewer (advisor).

2. Semi-quantitative evaluation

Semi-quantitative evaluation can be used for assessing small concept maps and for small numbers of maps. With this type of evaluation, several simple variables are calculated (number of all the propositions, number of correct propositions). Since everything has to be evaluated manually, this type of evaluation is very time-consuming and therefore not suitable for evaluating large numbers of concept maps.

3. Computer-aided quantitative evaluation

Computer-aided quantitative evaluation can also be used for large maps and large numbers of maps. Before evaluation can be carried out on a computer, the information from the concept maps must be entered into the computer. Special computer programs can be used for this in order to reduce the time involved and input errors, yet it is still too time-consuming for using in everyday school life. Computer-aided quantitative evaluation is very suitable for using in research.

4. Quantitative evaluation by computer only

Quantitative evaluation by computer is the most efficient type of evaluation. This type of evaluation can, however, only be carried out if the concept maps are created on the computer itself. This type of evaluation rules out human input errors. It is suitable for using with a large number of maps and comprehensive maps as well. It is the only type of evaluation which, apart from using in research, is also suitable for using in schools as far as the time factor is concerned.

Although Ruiz-Primo and Shavelson (1996) show also the problems in using concept mapping as assessment tool, there are many studies showing that concept mapping is an appropriate tool for testing students achievement (McGaghie, et al, 2000; West at al, 2000; Fischler et al, 2001; Reiska 2005). Some of the studies also show that there is a high correlation between the concept mapping and other knowledge tests (Mikelskis, 1999) but some studies did not prove the correlation between concept map scores and e.g. multiple choice exam performance (McGaghie, et al, 2000).

Different levels of evaluation were used in education; however we could not find the fourth level of evaluation. The possible reason for this can be that there is no suitable evaluation tool for concept maps developed yet.

4 Study one: knowledge before and after instruction and relation between knowledge and taking action

This study aims at two interrelated main objectives. On the one hand we examine the - didactically constantly postulated, but rarely substantiated - relation of learning and acting on the basis of a determined instruction. On the other hand we are looking at this aim parallel on the basis of several learning matters which differ relevant to learning and acting. In this study verbalized knowledge (tests including concept mapping) and actions of the subjects (intervention in computer simulations together with the thinking aloud method) are established and recorded at two stages in a teaching phase which is significant both for society and for physics (energy consumption and energy supply). This is linked with teaching approaches (traditional German science teaching and teaching according to the Anglo-Saxon STS model: Science - Technology - Society).

5 Concept mapping in study one

The information processing approach in psychology and the constructivism which is very common in research of science teaching start out from a network of knowledge concepts. Therefore knowledge can be described e. g. in the form of directed graphs, the nodal points of which are concepts and the edges are relations between these concepts. The connection of two concepts each with a directed relation therefore represents a part of the subject's knowledge in form of a proposition. Such graphs can be ascertained relatively easily for different fields and can also be analyzed by using evaluation programs (entailing, however, great expenditure). In this context we refer to the papers of White and Gunstone, 1992, of Bonato, 1990, and of Weber, 1994, as well as to our own preliminary work.

In this study we used concept mapping to record students' knowledge before and after a teaching unit. 51 concepts and 10 relations were given and they were printed on self-adhesive labels (see Fig 1).

Figure 1. Data collection with concept mapping in study one

To be in a position to evaluate 130 extensive concept maps with maximally 51 concepts and 10 relations we raised, we elaborated our own evaluation procedure (see Fig. 2). As a connection we have a reference matrix of all 51 concepts where the relations are entered which a physicist would use. This matrix was created by expert rating in several stages. The concept maps of the subjects are initially transcribed into adjacency matrixes. Afterwards these matrixes are computer-aided analyzed. It was our initial idea to evaluate the nets with the help of the graph analysis program GRADAP. We found corresponding suggestions in Bonato (1990) and Weber

(1994). As GRADAP is not very user-friendly and neutral concerning the content, in our evaluation procedure this program became a preliminary stage of the program CMVARI which we developed (Reiska 1997).

With this method we were able to reduce the time required to evaluate the maps, but it still has some weak points. The most important one is that the evaluation of the maps is still very time-consuming. This is one of the main reasons why concept mapping is still not very often used in schools for assessment.

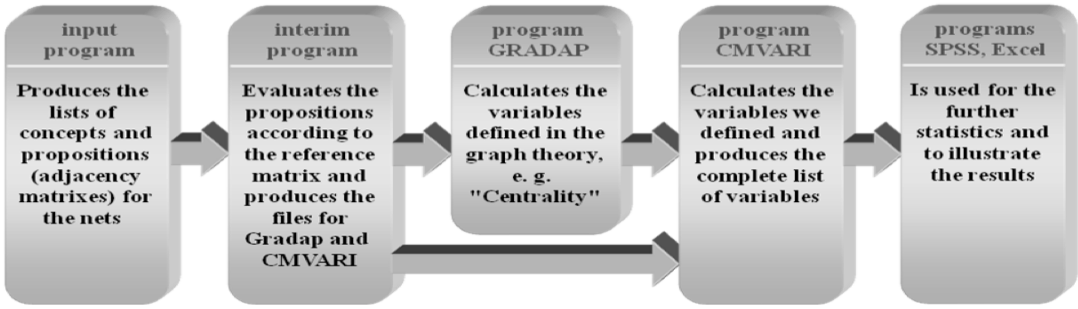

Figure 2. The evaluation procedure for concept maps.

6 Results of the first study

It was possible to prove by means of concept mapping that there had been a learning effect in the student groups with the instruction programs.

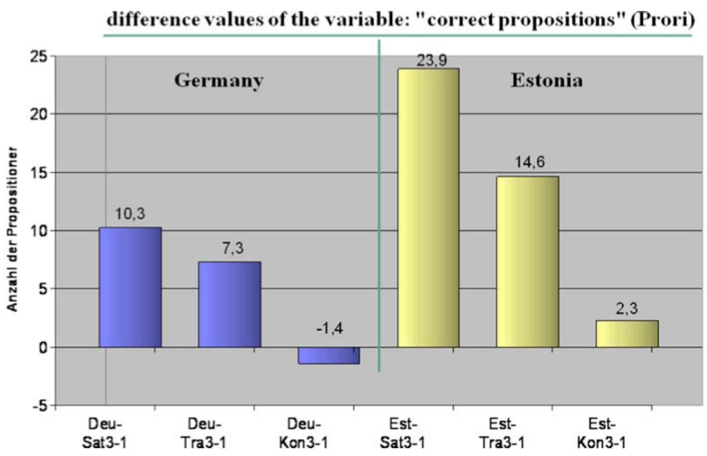

Figure 3. The increase of number of concepts in Germany and Estonia

We summarize our results in note form:

1. The increase of knowledge of the subjects we observed is indeed to be explained by the instruction.
2. The increase of knowledge depends on the teaching approach. It is larger in STS-teaching than in traditional teaching of physics, namely in the use of concepts of the terminology as well.
3. The school mark of the subject physics has only a minor prognostic worth concerning the increase of knowledge and the progress in acting.

According to the design of our study (Dahncke, 1996) before and after instruction the data is collected with the same procedure. Thus, we have a design of repeated measuring (see e.g. Bortz, 1985). Therefore, an evaluation procedure of several stages suggests itself. We combine this procedure with our own developments we outlined before which lead up to our programs CMVARI for concept mapping and SIMVARI for computer simulation. We are showing one example for concept in the different profundities of evaluation (MANOVA-procedure, LEAST SIGNIFICANT DIFFERENCE (LSD)-test and PARALLELING). Data collecting, processing and evaluation for the concept mapping is carried out in steps up to CMVARI, then we set up the averages for each variable in the groups and phases (see bar graph in fig. 4). In the further analysis we are looking with the MANOVA-procedure for the values which show significant differences between groups respectively phases (see * in the matrix of fig. 4. As an example we choose the variable „number of concepts from terminology“ because just in this field STS-teaching is often reproached with a deficit.

ZaFa	Average	0,31	0,40	0,38	0,65	0,67	0,39
Average		Sat1	Tra1	Kon1	Sat3	Tra3	Kon3
0,31	Sat1						
0,40	Tra1						
0,38	Kon1						
0,65	Sat3	*	*	*			
0,67	Tra3	*	*	*			
0,39	Kon3				*	*	

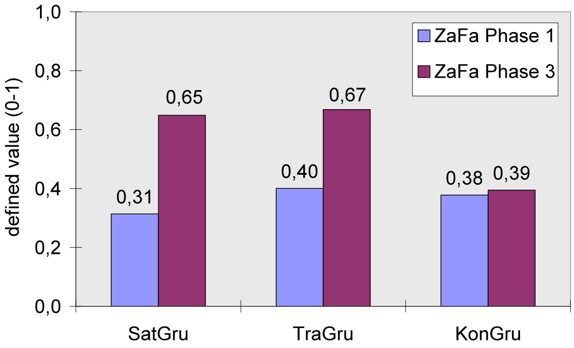

Figure 4. Variable: Number of concepts from terminology (ZaFa)

It turns out that the control groups achieve nearly no increase, both instructed groups achieve nearly equal increase. Therefore, with the LSD(p)-test on the level p=0,05 we are examining whether the differences of the single groups vary significantly.

The expected effect of instruction can be seen. The increases in the use of terminology are nearly the same for the SATIS-group and the traditional group (no significant difference), but they are significantly higher than of the control group (significant on the 5-%-level).
In summary may be stated: the more knowledge is shown during concept mapping, the more anticipating thinking, less mistakes and more reasonably economizing could be observed concerning the acting during the computer simulation.

7 Study two – learning physics and taking action

Although the competence to take action is postulated in most statements as an important objective of science teaching we don't have enough evidence of that. This is at least in part due to the fact that taking action of school students is difficult to observe and to record. In this field computer simulations can be helpful.

The subject matter of our project is the relation of learning and taking action. We examine this relation on the basis of examples from physics lessons, which belong to the concept of energy. Our methods of data acquisition comprise concept mapping, taking action as carrying out experiments and as intervention in computer simulation and the method of thinking aloud.

Progress in learning is established through differences in concept maps and in thinking aloud before and after lessons. We developed a computer program for concept mapping, CCMap, which enables the subjects to design the maps on screen. The results of our study in which we used about 200 maps designed by students confirm the advantages of using CCMap.

Taking action means in the understanding used in our studies that the subject makes a plan and follows it. Actions have to be elective, arbitrary and controlled. Following this criteria (Edelmann, 1996) we regard intervention in computer simulation and carrying out physics experiments as actions.

8 Concept mapping in study 2 - CCMap

For this study we developed a computer program for concept mapping, CCMap, which enables the subjects to design the maps on screen (Figure 5). In particular, the new method excludes the former weak points of concept mapping, thereby increasing its fields of application. In order to increase the screen area to maximum size, the bar of concepts was programmed in such a way that it is automatically scaled down if the number of concepts not yet used allows this. The bar of relations is only displayed if the user moves the mouse onto the bar of concepts. The user interface does not have complex structural menus. CCMap was developed in close cooperation with students at schools and universities in order to make it as user-friendly as possible.

An important feature of the researcher version of CCMap is the evaluation tool. It is possible to evaluate the maximum of 40 concept maps at the same time with CCMap. The maps are evaluated according to size, content and structure. In addition, MapChar, a variable made up of other variables, is calculated and visualized as a diagram. This variable is very suitable for grading students' performance at school. Evaluation of the maps with CCMap is based on a comparison of the maps with a reference map, i.e. the propositions from the students'

maps are compared with those of a reference matrix or list. If the corresponding reference matrix does not yet exist or is still not complete, it can be created or completed during evaluation.
Eight different variables for the maps will be calculated:

AlPro - Total number of propositions;
RiPro - Total number of correct propositions;
FQ - Error rate;
Fach - Correctness in physics (value from “0“ to “3“);
VNet - Integration;
Zent - Centrality of the map;
Insel - Number of sub maps (islands);
MapChar - Combined variable (combined from size, correctness and structure of the map).

The advantage of this method of evaluation is that a proposition only has to be evaluated once. The next time, the program automatically searches for the proposition in the reference matrix and subsequently applies it.

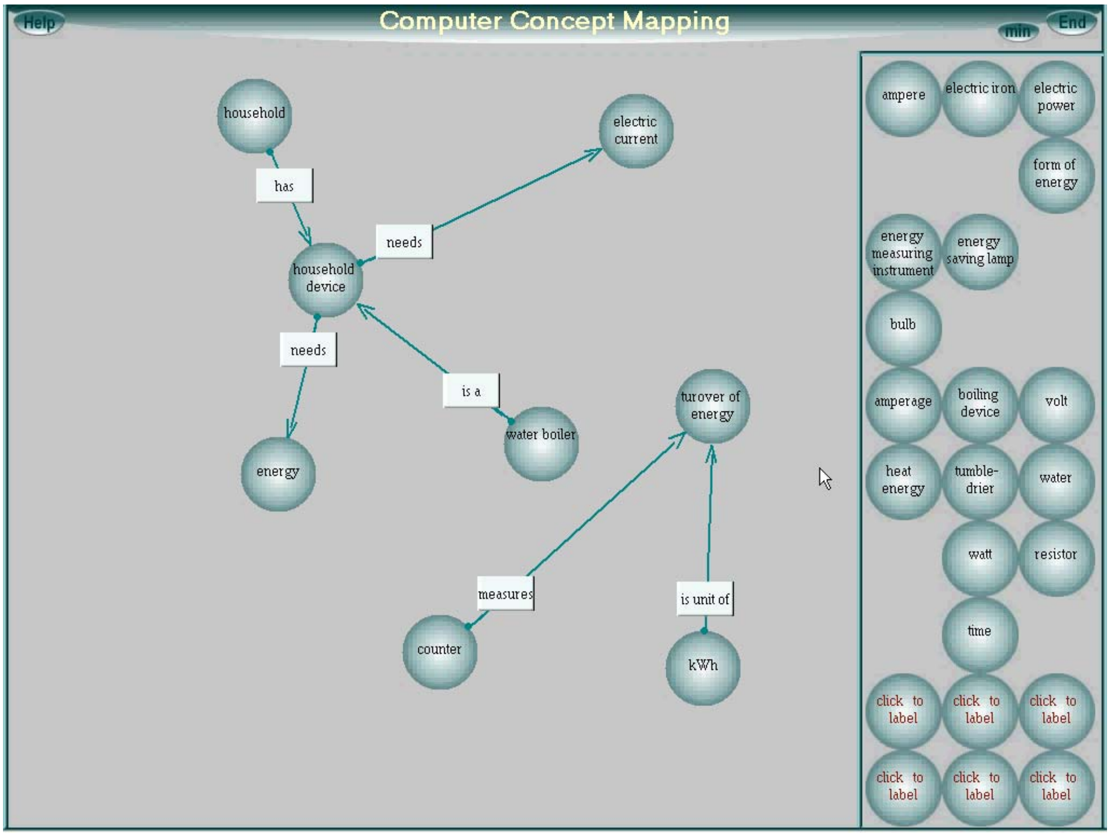

Figure 5. CCMap program

This means it is possible to generate a reference matrix file for each topic which can then be used repeatedly. When all the propositions have been evaluated, the variables are calculated on the basis of this evaluation.

With CCMap it is possible to calculate the compound variable MapChar. Since this variable is made up of several significant variables, it forms a sound basis for assessing students’ performance grades and also for illustrating the results.

9 Results of second study

Our results drawn from a sample of 100 9th graders show a strong impact of teaching on both types of taking action and that the actions themselves are learning situations which are at least as effective as learning in the classroom.

The concept maps show the effect of lessons (Fig. 5). Our findings also confirm that actions in the real situation and in computer simulation are learning situations. We compared the concept maps before and after taking action both in the STS group and in the control group (Fig. 6). Our combination of teaching and taking action leads to better knowledge than in control classes.

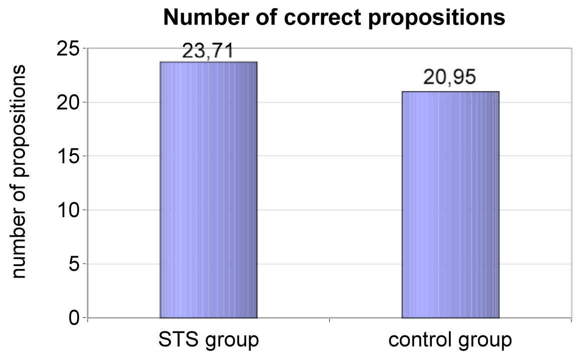

Figure. 5. Number of correct propositions

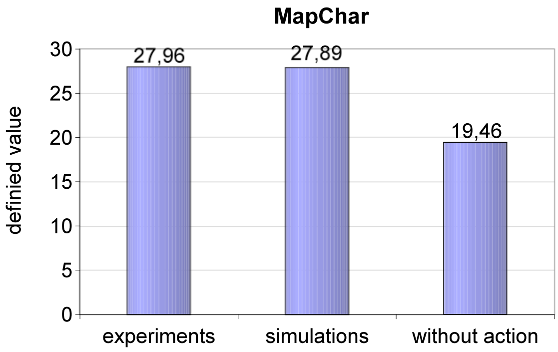

Figure 6. Increase in variable MapChar: Concept maps before and after experiment and computer simulation

10 Summary

Although in the literature we can find much criticism about validity and reliability by using concept mapping as an assessment tool (see e.g. Ruiz-Primo, Shavelson, 1996). Our studies showed that:

1. physics instructions have influence on knowledge measured with concept mapping;
2. different teaching methods have different influence on knowledge measured with concept mapping;
3. instructions about non-relevant topic don't have influence on knowledge measured with concept mapping;
4. there is a correlation between taking action and knowledge measured with concept mapping.

Based on these evidences we continue our research on concept mapping as an assessment tool in science education.

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