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CONCEPT MAPPING IN SCIENCE EDUCATION ASSESSMENT: AN APPROACH TO COMPUTER-SUPPORTED ACHIEVEMENT TESTS IN AN INTERDISCIPLINARY HYPERMEDIA LEARNING ENVIRONMENT

Steffen Schaal
University of Education Ludwigsburg, Germany

Abstract. The acquisition of conceptual knowledge is a central aim in science education. In this study, an interdisciplinary hypermedia-media assisted learning unit about hibernation and thermodynamics was developed and evaluated. But the assessment of interdisciplinary knowledge is not trivial. Therefore, concept mapping procedures were used to assess the cognitive effects within this complex knowledge domain. Learners constructed in a pre-post-test research design computer-supported concept maps, which were analysed with specific software. For data analysis, structural attributes and correspondence to a targeted reference map were used. The results showed higher-order domain-specific knowledge structures after the intervention, which indicate successful interdisciplinary learning with the hypermedia learning environment. In general, the benefit of computer-assisted concept mapping assessment for science education practice is discussed.

1 Introduction

1.1 Interdisciplinary Science Education and Hypermedia Learning

Science education deals with complex issues and requires multiple approaches for understanding. The acquisition of adequate conceptual knowledge implies the interconnection of scientific basic concepts and disciplines such as Biology and Physics. Subject-integrated approaches promote a learner’s cross-linked ability (Ballstaedt, 1995) and that is why enrolment in interdisciplinary courses may lead to a more complex thinking process and improve reasoning abilities by problem-solving activities and inquiry tasks (Bünder, 2003). However, within interdisciplinary instruction and subject-integrated approaches learners always have to cope with complex objectives. Mammalian hibernation, for instance, is such an interdisciplinary learning challenge. The essential concepts of thermodynamics have to be applied to mammals’ adaptation strategies to understand hibernation. But dealing with interdisciplinary topics implies a high cognitive load and should respect learners’ needs as well as their preconcepts about thermodynamics.

In a stricter sense, one can understand interdisciplinary learning as the construction of a suitable and sustainable knowledge structure applying methodology and language from more than one discipline to examine a central topic (Jacobs, 1989). This knowledge structure consists of interconnected concepts (e.g. about thermodynamics) and provides a basis for conceptual understanding or meaningful learning. Meaningful learning occurs when individuals "choose to relate new knowledge to relevant concepts and propositions they already know" (Novak & Gowin, 1984, p. 7). Hypermedia learning environments help to construct knowledge within complex domains (Spiro et al., 1992). But hypermedia learning material ought to be adequately structured taking into consideration a learner’s expertise, his/ her prior knowledge and computer-literacy as well (Weidenmann, 2001, Kerres, 2000). Within hypermedia learning environments learners have self-directed access to information units and can flexibly arrange their learning process in accordance with individual demands (Yildirim, Ozden & Aksu, 2001). Information is represented multimodal (visual & oral) and in multiple coding systems such as images, texts, text-/ image-combinations, graphs, tables, animations, films in order to be adequately mentally processed. Interactivity promotes a construction of active knowledge entities and reduces the danger of producing just inert knowledge (Schulmeister, 2002).
In this study, the focus is on the construction of conceptual knowledge about ‘Life in Winter’ and interrelated scientific concepts with an hypermedia learning environment for science education classroom (see detailed in Girwidz et al., 2006). Information about heat flow, energy transfer and hibernation of mammals is presented in a multifaceted learning environment fostering active knowledge acquisition. Two learners cooperatively work through information pages, animations, videos or simulations using an external workbook with a couple of sub-tasks. Far beyond simple memorizing or learning names of concepts, they gather knowledge with the real-life objective to finally “create” a virtual mammal for successful hibernation. The interrelation of biological aspects and thermodynamic fundamentals is exemplified at the beginning of every learning unit by a short video and has to be applied at this final task.

1.2 Concept Map Assessment

Interdisciplinary achievement and cumulative learning in complex knowledge domains are difficult to assess: Traditional test formats often tend to fail, especially when reading literacy or verbalisation skills require more effort than applying the actual states of knowledge (Goldsmith & Johnson, 1990, White & Gunstone, 1992). Therefore, concept mapping assessment may provide an alternative way to approach teaching as well as an additional method in educational research (e.g. Lin & Hu, 2003, Mitzes, Wandersee & Novak, 2001, Mc Clure, Sonak & Suen, 1999).

A consistent knowledge structure is essential for conceptual understanding, especially in complex and interdisciplinary knowledge domains. Thus, the interrelationship of concepts is seen as a fundamental attribute of knowledge. However, constructing concept maps needs to translate relevant cognitive structures into external networks which allow an interpretation of knowledge coherencies (Naveh-Benjamin & Lin, 1994). Concept maps can externalise an individual's recent standard of knowledge into a structured network of concepts, relationships or propositions (Novak, 1998). Consequently, changes of knowledge structures during an instruction can signal successful learning (Barney, Mintzes & Yen 2005, Engelbrecht et al., 2005, Yin et al., 2005, Stracke, 2004, Kinchin, 2001) and the validity and reliability of concept mapping assessment has been properly explored (Rye & Rubba, 2002, Ruiz-Primo et al., 2001, Martin, Mintzes & Clavijo, 2000, Mc Clure, Sonak & Suen 1999, Eckert 1998).

Nevertheless, scoring learners' concept maps for assessment is an often discussed issue and various methodological approaches are described in the literature. For instance, qualitative relational methods target the accuracy of each proposition; quantitative structural methods score the valid components in comparison to an expert- or criterion map (Gouli et al., 2005). Novak and Gowin's scoring method (1984) is used frequently as a basis of assessment. Ruiz-Primo's (2004) approach reflected a student's topic knowledge compared to an expert's structure with regard to an increasing expertise. Additionally, she distinguished concept maps by the different degrees of directedness (high-level directedness: Fill-in-the-Map; low-level directedness: Construct-a-Map without concepts provided) and pointed to three scoring systems: (1) of proposition accuracy, (2) of convergence with a criterion map and (3) of salience which is the "proportion of valid propositions out of all the propositions in the student's map" (Ruiz-Primo, 2000, p. 37). Ruiz-Primo and colleagues (2001) found correlations between this convergence score of construct-a-map procedures and learners' explanatory skills which gives evidence, that concept mapping assessment is "in fact measuring what is claimed" (p. 135). Mc Clure and colleagues (1999) compared holistic, relational and structural scoring methods without and with the use of a master map unveiling a high reliability for the latter. Thus, they recommend an assessment using master maps as compatible with science education practice.

The main objective of our study focussed on a concept map assessment within an interdisciplinary hypermedia-supported learning environment. We hypothesised that a learner's cooperative knowledge construction may lead to higher expertise in the specific domain of thermodynamics and hibernation. According to Bruhn and colleagues (2000) we chose dyads as empirical analyses' unity by focussing on the cooperative achievement and knowledge construction. The specific objectives of our present study were to monitor learners' skills and abilities in constructing integrated knowledge of mammalian hibernation strategies under biological and physical perspectives with the hypermedia environment. We used concept map scoring schemes which (i) score structural attributes and (ii) convergences with a criterion- or reference map.

2 Design and Procedures

2.1 Subjects and Intervention

Subjects were 9th graders at junior high schools (N = 106, age 15±1.2, medium stratification level, Realschule) working cooperatively in dyads (N = 53). The dyad formation itself was free of choice.

Each dyad worked with one notebook. The completion of a pre-test concept map with predetermined concepts and relations (T-1) included the monitoring of individual domain-specific prior knowledge and it became a part of the intervention itself. Pupils were guided through the hypermedia learning environment by an external workbook. Each dyad followed its appropriate individual working speed. The study program was completed within three days and consisted of six lessons. No further instruction or teacher support was provided. Immediately after the instruction the pupils completed a post-test concept map (T-2). For concept map assessment, a computer-software was used (MaNet® 1.6). All pupils were already familiar with this software; an assessment session in pre- and post-test was limited to 30 minutes each.

2.2 *Concept Mapping Assessment with MaNet® 1.6*

For analysis we used the software MaNet® (MaResCom, 2006) which allows a learner to construct concept maps intuitively on-screen, either with or without given concepts and relations. Furthermore, it allows a researcher to apply different automated scoring schemes. For our present study, predetermined concepts (eg. "a high temperature difference") had to be connected with a set of specific and directed relations (eg. "…leads to…"). Monitoring learners' interdisciplinary achievement needs a multidimensional assessment. Hence, differentiated analyses consider both structural attributes and correspondences with a reference map.

2.2.1 Scoring structural attributes

Scoring the concept maps by structural features before and after an intervention allows drawing conclusions about general achievement (see detailed in Eckert, 1998, Stracke, 2004). For our present study, the relevant structural attributes were (i) the 'volume' of a concept map (≙ total number of relations used in the learners' concept map), (ii) the 'ruggedness' which is the division of a concept map into un-connected sub-maps (Bonato, 1990) as well as (iii) the amount of accurate propositions in relation to the volume.

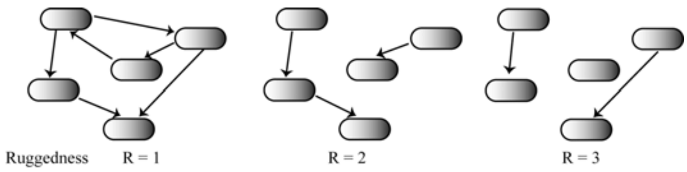

Figure 1. Ruggedness of a concept map

We followed the underlying theoretical assumption that an increase in knowledge structures' quality is related to a higher-order cross-linking between relevant concepts: Thus, a low ruggedness is considered as an indicator for a consistent knowledge structure (Bonato, 1990). However, a successful achievement might be imprecisely detailed since decreasing ruggedness or increasing volume do not allow any concrete conclusion about the concepts' appropriateness. As concept mapping assessment in this present study emphasizes more differentiated research questions, other scoring methods should be applied using a criterion- or reference map based on the intended learning target.

2.2.2 Scoring correspondence to a reference map

Corresponding a learner's concept map with an expert's one is regarded as a valid and reliable scoring method (Stracke, 2004, McClure et al., 1999). Thus, the construction of a reliable reference map is the first important aspect. Therefore, a procedure respecting Stracke's (2004), Ruiz-Primo's (2000) and Rye & Rubba's (2002) findings was used by integrating learning target oriented approaches to construct a list of interdisciplinary key-concepts and relations:

1. Analysis of learning target	Researcher group consisting of three experienced teachers (biology, mathematics & physics) and two university professors (biology and physics) declared the most important achievement goals to understand the hibernation phenomenon.
2. Definition and selection of essential propositions	Each group member provides a list of most central propositions (concepts linked by labelled relations) in the domain of thermodynamics (eg. "great body surface increases the energy transfer by conduction"). Then, a list of key-concepts and relations is created.
3. Construction of a reference map	The research group cooperatively constructs a common reference map with the concept- and relation-list.
4. Experts' individual concept map	Four other autonomous university teachers and professors (three biology and one physics) constructed an individual concept map using the provided concepts and links.
5. Validation of the reference map	The research group expert map and the average map of the four the autonomous experts are compared. The reference map showed an accordance of 89 %.
6. Using the research group map as reference- or criterion map	

Table 1. Adapted procedure for criterion map construction (Schaal, 2006).

In this study, each assessment concept map included a total of nineteen concepts and six labelled relations. A coefficient of correspondence, which is calculated based on an inter-relational matrix, allows a comparison of a learner's concept map to the reference map (Eckert 1998, 2000):
Two concepts are …

in the learner's map		*in the expert map*	*label*
not connected	and also	not connected	cnc (correctly not connected)
not connected	but	connected	mc (missing connection)
connected	but	not connected	wc (wrong connection)
connected	and also	connected	cc (correct connection)

Table 2. Matrix of interrelations within a concept map

The coefficient of correspondence C is calculated by the formula

$$C_w = \frac{\sum cnc + \sum cc - \left(\sum mc + \sum wc\right)}{\text{maximal amount of interconnections possible}}$$

The value of this coefficient is between -1 and 1. The value -1 means an absolute negative of the reference map and the value 1 is consequently the result, if a learner's map is identical to the reference map. The coefficient of 0 is reached if there are as many wrong/ missing connections as correct connections/ correctly not connected links. The coefficient of correspondence is computed automatically with the MaNet® software in comparison to the reference map.

The similarity or correspondence to a reference map can be assigned to different criteria of increasing rigour:

- a link is considered as undirected and unlabeled (C_1). Every accurate link between two or more concepts is considered as valid,
- a link is considered as undirected, but labelled correctly (C_2). Links are counted, if the label is accurate,
- a link is considered as directed and labelled correctly (C_3). Links are only counted, if the direction and the label are accurate.

In addition to an 'ordinary' correspondence the comparison of two concept maps can also be conducted considering a kind of weighted procedure: For instance, an accurate proposition in a rarely linked concept map scores higher than a proposition in one with a high volume. Therefore, a weighted coefficient of correspondence (C_w) should be used. The weighting factor W is defined as

$$W_1 = \frac{\sum \text{correctly connected in reference map}}{\sum \text{correctly not-connected in reference map}} \text{ and } W_2 = \frac{1}{W_1}.$$

As a consequence, the formula for the calculation of the weighted coefficient of correspondence is modified:

$$C_w = \frac{W_1 \cdot \sum cnc + W_2 \cdot \sum cc - \left(W_1 \cdot \sum mc + W_2 \cdot \sum wc\right)}{\text{maximal amount of interconnections possible}}$$

The values of the C_w are also between -1 and +1, in general they are lower than the unweighted ones. Thus, the comparison of two concept maps with the weighted coefficient of correspondence can be considered as more rigorous than the unweighted one (Stracke, 2004). Therefore, in this study only the weighted coefficients are used for empirical evaluation.

3 Results

Two main hypotheses were tested:

(i) The structural attributes of a learner's concept map score higher after cooperative working with our hypermedia learning environment.
(ii) A learner's concept map increasingly adjusts to an expert's domain structure.

As some variables were not normally distributed (Kolmogorov-Smirnov: pretest: Volume $U = 1.49$, $p < .05$; ruggedness $Z = 1.85$, $p < .01$. C_2 $Z = 1,.57$, $p < .05$; posttest: C_{2w} $Z = 1.55$, $p < .05$), we applied non-parametric procedures (*cf.* Bortz & Döring, 2002).

3.1 Achievement- structural attributes

In general, post-test concept maps showed a higher consistency and interconnectedness compared to pre-test. Structural attributes strongly differed before and after the intervention: the number of relations in the post-test increased while the ruggedness of learners' concept maps decreased. The concept maps emerged from a status of separated submaps towards a more consistent pattern. Both its volume and the amount of accurate propositions also increased (Fig. 2).

N = 53	R+	R-	Z	Sig.(2-tailed)
Volume	24.1	48.1	-4.8	p < .001
Ruggedness	37.7	15.8	-5.2	p < .005
Accurate propositions	0.0	47.5	-8.7	p < .005

Table 3. Paired-sample Wilcoxon-test for structural attributes in pre- and post-test.

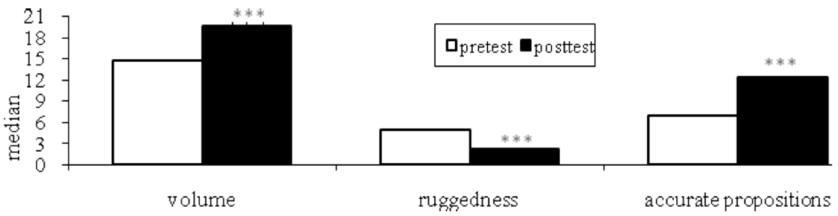

Figure 2. Achievement according to structural attributes (*** = p < .001; 2-tailed) (N=53)

The quotient score of accurate propositions relative to the volume also increased from pre- to post-test (Wilcoxon: Z = -6,91; p < .001). Therefore, the first hypothesis (i) concerning the increase of structural attributes through cooperative working with the hypermedia learning environment has to be accepted.

3.2 Achievement – analysis of correspondence

For further analysis of a learner's concept map relationship with reference maps, weighted procedures were introduced. These procedures are considered to assess content-oriented relational correspondence objectively (Stracke, 2004).

	pre-test		***post-test***	
	Median	*SD*	*Median*	*SD*
simple correspondence C_{1w}	-0,30	*0,12*	-0,15	0,14
medium correspondence C_{2w}	-0,42	*0,11*	-0,30	0,17
rigorous correspondence C_{3w}	-0,45	*0,10*	-0,32	0,15

Table 4. Medians of coefficients of correspondence (N = 53).

The coefficients of correspondence showed increasing achievement from pre- to post-test: Figure 3 indicates the increase pattern ($C_{1\text{-}3w}$). As expected, the C_{3w}-values scored lowest.

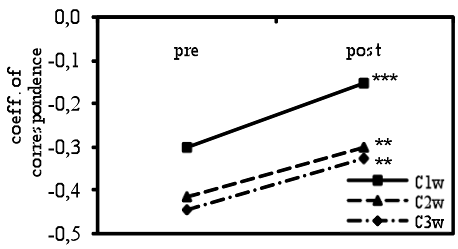

Figure 3. Increase of correspondence from pre- to post-test
(** = p < .005; *** = p < .001; two-tailed significance)

N = 53	R+	R-	Z	Sig.(2-tailed)
simple correspondence C_{1w}	17.7	30.9	-4.2	p < .001
Medium correspondence C_{2w}	22.6	22.6	-3.1	p < .005
rigorous correspondence C_{3w}	22.4	29.0	-3.2	p < .005

Table 5. Paired-sample Wilcoxon-test for coefficient of correspondence in pre- and post-test.

A learner's concept map matches closer the reference map due to instruction. Thus, the second hypothesis (ii) has to be confirmed. This increase of correspondence is proportional to at least three to five additional central propositions (each consisting of at least two concepts and a relation) from pre- to post-test.

4 Discussion

Concept mapping offers a suitable method for assessing important learning effects within classrooms. Learners' concept maps became more consistent, more elaborated and showed more appropriate linkages between the miscellaneous concepts after the learning unit in this study. In general, the maps improved, getting a higher similarity with an expert's reference map respecting interdisciplinary cross-linking. Thus, learners developed adequate structural knowledge about hibernation from pre- to post-test. Consistently with previous studies the complexity of the knowledge structures also increased (c.f. Barney, Mintzes & Yen, 2005; Engelbrecht et al., 2005). In summary, our hypermedia learning environment supported the construction of an interdisciplinary knowledge structure based on interrelated concepts of biology and thermodynamics. Due to the enduring lack of empirical achievement data in interdisciplinary learning settings (e.g. Stevens et al., 2005) we consider this finding to be important.

Concerning the hypermedia learning environment, pupils solved problems cooperatively on their own and they had to overcome various learning obstacles. Obviously they performed quite well during the computer-supported lessons and could adequately accomplish a self-determined learning approach. These results are in line with previous studies. For instance, Yildirim and colleagues (2001) compared traditional media and hypermedia environments regarding knowledge acquisition and retention effects and revealed this as an appropriate basis to acquire sufficient knowledge. The time-consuming instruction of biological and physical basic concepts, in our case of hibernation, can be shortened and thus, the time for experimental and problem-solving hands-on activities increases. Klahr, Triona and Williams (2006), for instance, compared the educational effectiveness of virtual versus physical materials; they described virtual learning materials as producing similar gains with regard to acquired knowledge and student's self-confidence. Thus, virtual learning material can additionally attribute to knowledge improvement, but, of course, cannot substitute the very specific advantage of hands-on activities. Nevertheless, it provides a very helpful tool to supplement other approaches. Even so, when arrangements about conceptual knowledge are enforced (as in the present study) comparable prior knowledge seems to be important for joint interaction and becomes a relevant factor for learning. This aspect might be measured by traditional school grades which will be presented more detailed in Schaal and colleagues (2008).

Our learner's dyads constructed their concept maps very quickly and efficiently by using the computer-based concept mapping program. The computer assisted empirical analysis of learners' concept maps clearly showed learning effects and allowed a direct interpretation. Paper-and-pencil concept mapping often has to cope with practical problems like, for instance, irreversibility of drawn proposition, difficulties with erasing or adding concepts and relations in a pre-existing map, 'translation'- or interpretation-errors. However, constructing concept maps on-screen was efficient and very intuitive for our learners. Furthermore, a comparison of concept map data used in this study and the data of the former study mentioned above (Girwidz et al., 2006) showed similar tendencies in individual learning, but also further ongoing aspects about knowledge structures. Consistent results about retention and conceptual knowledge were found, indicating a sufficient validity of the procedure for those aspects. However, most important is the innovative possibility to get insights into structural aspects of our learners' knowledge and linkage of concepts. Nevertheless, concept map assessment still is not a common tool in the scientific community and more experience is needed.

5 Outlook and consequences

This study shows the potential of a specific interdisciplinary approach providing adequate interconnected knowledge about a specific topic by using hypermedia. This might be also true for other interdisciplinary domains in science education, for example, the visual perception (c.f. Schaal & Bogner, 2005), or biotechnology. Interactive and self-determined computer-supported learning settings can perform more authentic problem-based learning scenarios. A hypermedia learning environment allows interactive manipulation of virtual objects, e. g. lenses, animals' eyes and optical illusions. In contrast to that, traditional media or audio-visual media can hardly overcome passive learning (Berck, 2005). Although our interpretation is still tentative and needs further research, other computer-based learning studies point into this direction, too.

It is a question whether learners of middle-stratification can cope with both demands, the interdisciplinary science education and the hypermedia learning at the same time. Nevertheless, the application of computer-assisted concept map assessment is an easy, time-sensible and reliable approach, offering supplementary and substantial innovations to conventional paper-and-pencil tests. Science educators in every-day classrooms can easily assess an achievement by using concept maps. Comparing reference maps with individual maps of students may even become a learning target. Thus, a computer-supported concept mapping may profit every-day courses.

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References

Ballstaedt, S. (1995). Interdisziplinäres Lernen: Aspekte des fächerverbindenden Unterrichts. Tübingen: DIFF.

Barney, E., Mintzes, J. & Yen, C-F (2005). Assessing knowledge, attitudes and behavior toward charismatic megafauna: The case of dolphins. Journal of Environmental Education, 36, 41-55.

Berck, K.-H. (2005). Biologiedidaktik. Wiebelsheim: Quelle & Meyer.

Bonato, M. (1990). Wissensstrukturierung mittels Struktur-Lege-Techniken. Eine graphentheoretische Analyse von Wissensnetzen. Frankfurt/M.: Peter Lang.

Bortz, J. & Döring, N. (2002). Forschungsmethoden und Evaluation für Human- und Sozialwissenschaftler. Heidelberg: Springer.

Bruhn, J., Fischer, F., Gräsel, C. & Mandl, H. (2000). Kooperatives Lernen mit Mapping-Techniken. In H. Mandl, & F. Fischer (Eds.), Wissen sichtbar machen. Wissensmanagement mit Mapping-Techniken (pp. 119-133). Göttingen: Hogrefe.

Bünder, W. (2003). PING: Beispiel "Ökologisches Wohnen". Fragen stellen, untersuchen, erklären und sein Wissen nutzen: wissenschaftliches Arbeiten im naturwissenschaftlichen Unterricht. Naturwissenschaften im Unterricht - Physik, 74, 9-11.

Eckert, A. (1998). Kognition und Wissensdiagnose: Die Entwicklung und empirische Überprüfung des computerunterstützten wissensdiagnostischen Instrumentariums Netzwerk-Elaborierungs-Technik (NET). Lengerich, Berlin: Pabst.

Eckert, A. (2000). Die Netzwerk-Elaborations-Technik (NET) – Ein computerunterstütztes Verfahren zur Diagnose komplexer Wissensstrukturen. In H. Mandl, & F. Fischer (Eds.), Wissen sichtbar machen. Wissensmanagement mit Mapping-Techniken (pp. 137-157). Göttingen: Hogrefe.

Engelbrecht, A., Mintzes, J., Brown, L. & Kelso, P. (2005). Probing Understanding in Physical Geology Using Concept Maps and Clinical Interviews. Journal of Geoscience Education, 53, 263-270.

Girwidz, R., Bogner, F.X, Rubitzko, T. & Schaal, S. (2006). Media Assisted Learning in Science Education: An interdisciplinary approach to hibernation and energy transfer. Science Education International, 17, 95-107.

Goldsmith, T. & Johnson, P. (1990). A structural assessment of classroom learning. In R. Schvaneveldt (Ed.), Pathfinder associative networks: Studies in knowledge organization (pp. 241-254). Norwood, NJ: Abl.

Gouli, E., Gogoulou, A., Papanikolaou, K. & Griggoriadou, M. (2005). How to Qualitatively + Quantitatively Assess Concepts Maps: the case of COMPASS. In C.-K. Looi et al. (Eds.), Artificial Intelligence in Education (pp. 804-806). Athens: IOS Press.

Jacobs, H. (1989). Interdisciplinary Curriculum: Design and Implementation. Alexandria: ASCD.

Kerres, M. (2000). Mediendidaktische Analyse digitaler Medien im Unterricht. Computer und Unterricht, 37, 26-28.

Kinchin, I. (2001). If concept mapping is so helpful to learning biology, why aren't we all doing it? International Journal of Science Education, 23, 1257-1269.

Klahr, D., Triona, L. & Williams, C. (2006). Hands-on what? The relative effectiviness of physical versus virtual materials in an engeneering design project by middle school children. Journal of Research in Science Teaching, 44, 183-203.

Lin, C.-Y. & Hu, R. (2003). Students' understanding of energy flow and matter cycling in the context of the food chain, photosynthesis and respiration. International Journal of Science Education, 25, 1529-1544.

Marescom (2006). MaNet 1.6.4. Software for Concept Mapping Assessment. http://www.marescom.net, version dated: march, 17th 2008.

Martin, B., Mintzes, J. & Clavijo, I. (2000). Restructuring knowledge in biology: Cognitive processes and metacognitive reflections. International Journal of Science Education, 3, 303-323.

McClure, J., Sonak, B. & Suen, H. (1999). Concept Map Assessment of Classroom Learning: Reliability, Validità and Logistical Practicality. Journal of Research in Science Teaching, 36, 475-492.

Mintzes, J., Wandersee, J. & Novak, J. D. (2001). Assessing understanding in biology. Journal of Biological Education, 35, 118-124.

Naveh-Benjamin, M., Lin, Y., & McKeachie, W. (1995). Inferring students' cognitive structures and their development using the "Fill-in-the-Structure" (FITS) technique. In P. Nichols, F. Chipman & R. Brennan (Eds.), Cognitively diagnostic assessment (pp. 279-304). Hillsdale, NJ: Lawrence Erlbaum.

Novak, J. & D. Gowin. (1984). Learning How to Learn. New York: Cambridge University Press.

Novak, J. D. (1990). Concept mapping: A useful tool for science education. Journal of Research in Science Teaching, 10, 923–949.

Novak, J. D. (1998). Learning, Creating and Using Knowledge: Concept Maps as Facilitative Tools in Schools and Corporations. Mahwah, NJ: Lawrence, Erlbaum.

Ruiz-Primo, M. (2000). On the use of concept maps as an assessment tool in Science: What we have learned so far. Revista Electrónica de Investigación Educativa, 2, 29-52.

Ruiz-Primo, M. (2004). Examining concept maps as an assessment tool. In A. J. Cañas, J. D. Novak, & F. M. González. (Eds), Concept Maps: Theory, Methodology, Technology. Proceedings of the First International Conference on Concept Mapping (pp. 555-562). Pamplona: Universidad Pública de Navarra.

Ruiz-Primo, M., Schultz, S., Li, M., & Shavelson, R. (2001). Comparison of the reliability and validity of scores from two concept-mapping techniques. Journal of Research in Science Teaching, 38, 260–278.

Rye, J. & Rubba, P. (2002). Scoring Concept Maps: An Expert Map-Based Scheme Weighted for Relationships. School Science & Mathematics, 102, 33-44.

Schaal, S. (2006). Fachintegratives Lernen mit digitalen Medien. Die theoriegeleitete Entwicklung und Evaluation einer hypermedialen Lernumgebung für den naturwissenschaftlichen Unterricht. Hamburg: Kovac.

Schaal, S. & Bogner, F. (2005). Human visual perception – learning at workstations. Journal of Biological Education, 40, 32-37.

Schaal, Bogner & Girwidz (2008). Concept Mapping Assessment of Media Assisted Learning in Interdisciplinary Science Education, Research in Science Education, accepted.

Schulmeister, R. (2002). Grundlagen hypermedialer Lernsysteme - Theorie, Didaktik, Design. München: Oldenbourg.

Spiro, R., Feltovich, P., Jacobson, M. & Coulson, R. (1992). Cognitive flexibility, constructivism and hypertext: Random access instruction for advanced knowledge acquisition in ill-structured domains. (In T. Duffy & D. Jonassen (Eds.), Constructivism and Technology of Instruction (pp. 57-76). Hillsdale, NJ: Erlbaum.

Stevens, R., Wineburg, S., Herrenkohl, L. R. & Bell, P. (2005). The comparative understanding of school subjects: Past, present, and future research agenda. Review of Educational Research, 75, 13-35.

Stracke, I. (2004). Einsatz computerbasierter Concept Maps zur Wissensdiagnose in der Chemie. Münster: Waxmann.

Weidenmann, B. (2001). Lehr-Lernforschung und neue Medien. In B. Herzig (Ed.), Medien machen Schule. Grundlagen, Konzepte und Erfahrungen zu Medienbildung (pp. 89-1089). Bad Heilbrunn: Klinkardt.

White R. & Gunstone, R. (1992). Probing Understanding. London: The Falmer Press.

Yildirim, Z., Ozden, M. Y. & Aksu, M. (2001). Comparison of hypermedia learning and traditional instruction on knowledge acquisition and retention. Journal of Educational Research, 94, 207-214.

Yin, Y., Vanides, J., Ruiz-Primo, M., Ayala, C., & Shavelson, R. (2005). Comparison of Two Concept-Mapping Techniques: Implications for Scoring, Interpretation and Use. Journal of Research in Science Teaching, 42, 166-184.