Learning Effectiveness of Concept Mapping in a Computer Supported Collaborative Problem Solving Design

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Abstract

The paper presents an experimental study aimed at investigating the learning effectiveness of concept mapping in a computer supported collaborative problem solving design. The main assumption underlying this research is that shared cognition is a substantial for cognitive construction and reconstruction and that concept mapping is an effective tool for mediating computer supported collaboration.

Based on the assumption that the form in which knowledge is shared influence strongly the process of building a shared cognition and hence – the effectiveness of collaborative learning, three scenarios of concept mapping mediated group interaction have been designed – Distributed, Moderated and Shared. These tree scenarios demonstrated differential effect towards different aspects of learning effectiveness both at a group and at an individual level. It is concluded that the mode of sharing and the form of knowledge, which students communicate are more important than the access to the distributed resources itself. The Sharing scenarios showed to be the most appropriate for establishing a supportive learning environment in computer supported collaborative problem solving.

Keywords: shared cognition, distributed cognition, collaborative scenarios, concept mapping, learning effectiveness

1. Theoretical background and research rationality

Different theoretical perspectives emphasise collaboration as a successful and powerful activity for learning and problem solving. In collaborative learning students discover, construct and become aware of their own cognitive structures by representing and explaining their concepts and ideas. Collaboration presents divergent ways people think and prompts different perspectives to the problem. This provokes breaking of existing cognitive patterns and stimulates critical and creative thinking.

Two concepts and research paradigms are closely related to the problem area of collaborative learning - *distributed cognition* and *shared cognition*. A distinction between the two should be made although some people use them interchangeably.

Distributed cognition is defined as an extension of the internal cognition of the personality in outside world (artefacts and other people). It creates 'person-plus' cognition (Perkins, 1993). In teams distributed cognition is concerned with representation and access of the other people knowledge (Hutchins, 1990). For each student in a group the presentation of the others is a distributed resource for constructing and reconstructing his/her own cognition.

Shared cognition is building upon the individual inputs in the collaborative process. Representing their cognitive structures and negotiating the meaning of concepts, individuals reach by their interaction a common vision on the problem. Essential feature of collaborative learning is the process of interaction between individual cognitions and between individual cognitions and shared group cognition that Salomon (1993) defines as interdependence. It is emphasised that reconstruction of individual cognition requires a profound and mutual understanding of collaborators' perspectives and shared interpretations of the problem. Only the knowledge that is meaningful for individuals is internalised. Solomon (2000) stresses that knowledge is always part of a context. It is very important that cooperating subjects acquire a common frame of reference in order to communicate their individual viewpoints. Shared cognition is at the same way a group and an individual property and posses personal meaning for each student. All object of the shared cognition and all pieces of knowledge are meaningfully integrated in the cognitive structure of collaborating persons and are interpreted on the similar frame of reference.

Concept mapping fails into the large category of mediating tools. The concept of mediation refers to the fact that our relation with the outside world (including the other people) is always mediated by signs and artefacts. According to Jonassen and Marra (1994) concept maps is a kind of Mindtools that enhance our understanding of how learners organise and use knowledge. Mindtools, otherwise known as cognitive tools (Kommers, Jonassen, & Mayes, 1991) are intended to engage and facilitate cognitive processing.

An important advantage of concept mapping is that it models the way human mind organizes knowledge. According to Solomon (2000) one of the main distinctions between information and knowledge is that while information is discrete, knowledge is arranged in networks with meaningful connections between nodes. While information can be transmitted as it is, knowledge needs to be constructed as a web of meaningful connections.

Concept mapping offers a close correspondence between psychological constructs and their external mode of representations. It uses a simple formal convention - nodes, links and labels on the links, integrates two kinds of coding - verbal and visual, externalises both cognitive and affective processes, stimulates self-appraisal and self-reflection and supports mental imagery (Stoyanov & Kommers, 1999)

Some distinctive features of concept mapping promote the assumption that it should be an effective technique for computer supported collaboration (Stoyanova, 2000).

- Concept mapping is a unique technique for externalising the cognitive structure of the students. Using concept mapping students communicate on the level of the *whole picture* of the problem space, representing their prior knowledge and vision. Explanations of and elaboration on the different perspectives based on concept mapping are much more full and comprehensive.
- Meanings of the concepts and ideas are *clearly defined* by the position of the concept in the whole picture and its interrelations with other concepts. This *facilitates the process of group negotiation of meaning and promotes a deeper mutual understanding* between collaborators. It is supposed that the process of group negotiation should be a shift for *internal negotiation* for students and meaningful integration of the new concepts in the cognitive structure of learners.
- Interacting by concept mapping, students have the possibilities to take a look at the *whole* problem space as it is *visualised by other* group members. It should enhance the process of *critical reflection* as well as *creative thinking.*

The main assumption underlying this research is that shared cognition in collaborative learning is a substantial for cognitive construction and reconstruction and that concept mapping is an effective tool for mediating shared cognition.

2. Experimental validation

An experimental study was undertaken in order to investigate the *learning effectiveness of concept mapping in a computer supported collaborative problem solving design and* how this effectiveness depends on the *mode of group interaction* in which concept mapping is used.

Collaborative scenarios

The hypothetical construct of the modes of collaborative interaction is based on the idea that knowledge exists in three forms: as individual mental constructs and precepts, as knowledge in action, and as knowledge embodied in artefacts (Hedlund & Nonaka, 1994).

Activity theory (Vygotsky, 1986; Leont'ev, 1978; Kuutti, 1991; Jonassen, 2000) characterises learning as an process of appropriation of the sociocultural meaning externalised in the artefacts. Learning is based on the adequate socially determined activity of a subject toward an object in which the knowledge is internalised in a meaningful way. It is supposed that sharing of the externalised knowledge (artefacts) creates a distributed cognition. Only sharing of knowledge in action, in other words sharing the process of learning itself, is a reliable base for developing a shared cognition. The shared meaning is generated through use (Pea, 1993)

Based on the assumption that the form in which knowledge is shared influence strongly the process of building a shared cognition and hence – the effectiveness of collaborative learning three scenarios of concept mapping mediated group interaction have been designed:

Distributed interaction. Group members work autonomously and produce intermediate artifacts (maps) embodying their knowledge and visions, which are passed to the other members. This circuit is repeated until all group members reach a common vision of the problem. The process of knowledge acquisition, creation and internalisation is individual.

Moderated interaction. Interaction process is facilitated by a group moderator (the role is taken by one of the group members) who is adjusting individually produced artifacts until a common group vision is reached. The representations of individual cognitive structures are not directly accessible but group members are involved in the process of negotiation of meanings and ideas that take place between them and the group moderator.

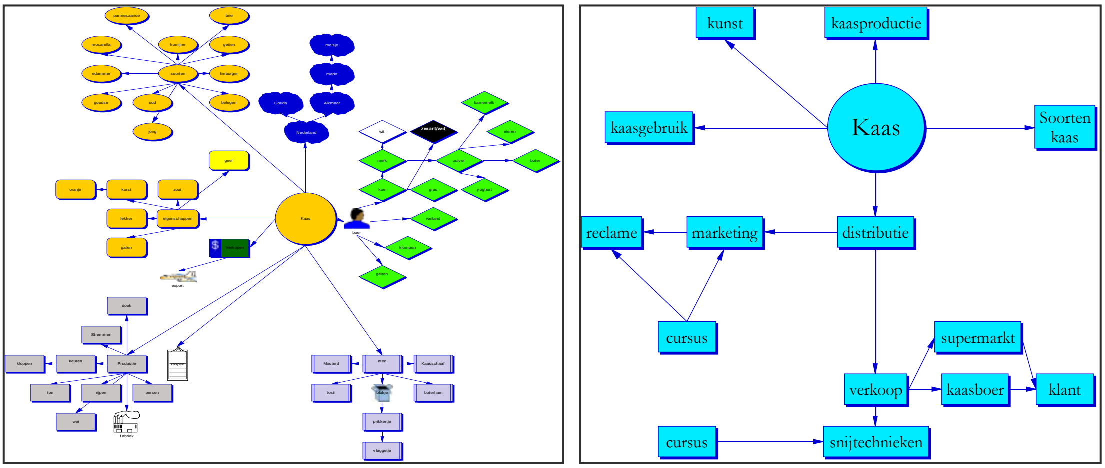
Shared interaction. Group members interact directly by synchronous activity and common efforts to solve the problem as a group. They share their knowledge in action. Knowledge is communicated in the process of its appropriation and creation. Collaborative actions of students are the individual inputs toward shared cognition.
In summary, the main assumption is that learning effectiveness as group and individual output depends significantly on the mode of concept mapping mediated group interaction. The three modes described above effect in a different way both the group and the individual learning effectiveness. Focusing on the higher order learning in an ill-structured problem situation the Sharing mode should be the most appropriate for establishing a supportive learning environment in problem solving design. It should enable the full potential of concept mapping method.

Experimental design
The experimental design is a random assignment pre-test post test control group.
Twenty-six students (6 groups) of University of Twente, Faculty of Educational Science and Technology, enrolled in 'Linear and Hypermedia' course, were selected as experimental subjects and were randomly assigned to four types of problem solving collaboration (mapping and control). Groups are distributed as follows:

- Distributed mapping mode – 2 groups;
- Moderated mapping mode – 1 group;
- Shared mapping mode – 2 groups;
- Control, non-mapping mode – 1 group. The control group was instructed to use Brainstorming method for their collaboration

The experiment took place during the design phase of the 'Linear and hypermedia' course. This course is project based, problem solving oriented and students centred. Students enrolled in the course are to design and produce a multimedia (hypermedia) product on the topic 'Cheese and cheese production'. During the first frontal session of the course students were introduced briefly with concept mapping technique and with Inspiration concept mapping software.
The experimental procedure consist of three main parts

- Pre-test. Before the experimental session a pre-test was conducted as an individual task. Students were asked to make a paper and pencil concept map representing their personal knowledge, vision and understanding of the task. Before the collaborative experimental session all pre-test CM were collected.
- Collaborative experimental session. Students were assigned to the groups and receive written instructions how to proceed their group work. The task of the collaborative session was to reach a common group vision (represented in map format for mapping groups and in an outline format for the control group) about the conceptual structure of the topic based on their prior knowledge and personal visions. Students were not recommended to search additional learning resources. The group outputs were collected. The sessions were audio- and videotaped.
- Post-test. In order to capture the individual learning outputs after the group work the same task as in the pre-test was proposed to the students a week after the experiment session. They were asked to make a concept map on the topic as an individual task.



Concept map drown by a group in the Shared mode   Concept map drown by a group in the Moderated mode

***Fig. 1**: Examples of group concept maps*

The **independent variables** are:

- the use of concept mapping technique in collaboration process with two levels – mapping and control groups
- the mode of group interaction with three levels - ‘Distributed’ ‘Moderated’ and ‘Shared’.

The **dependent variable** is the learning effectiveness of collaborative problem solving operationalised in tree dimensions as follows:

1. Learning effectiveness at the level of individual student, scored numerically on post-test concept mapping production in terms of:
   - fluency –the total number of nodes and links in an individual post-test, representative for student’s understanding about the problem.
   - flexibility –distribution of the concepts on different defined by the shortest link to the central concept.
   - enrichment – relative change of the number of concepts on the base of post-test – pre-test comparison (Enrichment = N_{nodes} post-test$_{(Sn)}$ – N_{nodes} pre-test$_{(Sn)}$)
   - knowledge acquisition –the number of the new concepts in a post-test.
   - retention –the number of concepts in the individual pre-test that are transferred to the same person’s post-test.
   - individual creativity – the new concepts and ideas generated individually after the collaboration.
   - reconfiguration – defined as the changes in the concepts’ structure.
2. Learning effectiveness at the level of the group as a whole, scored numerically on group concept mapping production in terms of:
   - fluency –the total number of concepts and links in the group problem solution.
   - flexibility – the distribution of concepts on different concept levels in relation to the central concept.
   - retention – contra indicated by the number of concepts and links in the group map that are not transferred to anyone of the individual post-test representation
   - group creativity – new concepts and ideas generated in the collaboration session.
3. Learning effectiveness as an interaction between individual students and group achievements, scored numerically on both individual and group in- and outputs in terms of:
   - individual-to-group transfer - individuals’ inputs in the group solution.
   - group-to-individual transfer - concepts that are transferred from the shared group cognition to the individual cognitions.

Data was analysed applying one-way ANOVA and covariation procedure by SPSS 9.0 statistical package. In order to define the specific differences between groups a Bonferroni post-hoc test of multiple comparison was conducted.

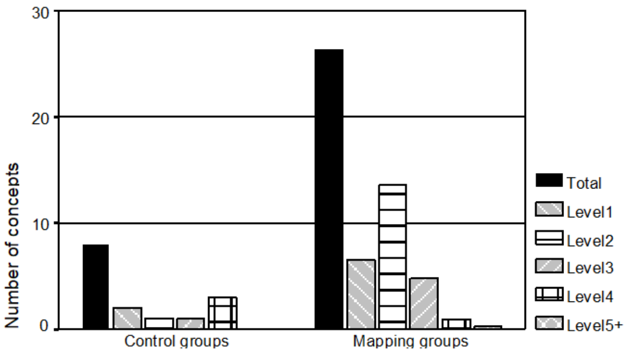
4. Concept mapping as a mediating tool for sharing cognition

Individual learning effectiveness

<u>Fluency and Flexibility</u>

A comparison between groups that have used mapping technique and the control group that have used brainstorming technique reveals that concept-mapping technique influence strongly the conceptual fluency as a parameter of the individual learning effectiveness (M_{map} = 26.41; $M_{contr.}$ = 8.00; F = 7.395, Sig. = .014). Students in concept mapping groups showed better results in their post-test as a total number of concepts covered in the problem space that students in the control group.

Distribution on concept levels shows a difference that is significant at Level 1 (M_{map} = 6.47; $M_{contr.}$ = 2.00; F = 4.837, Sig. = .040), Level 2 (M_{map} = 13.59; $M_{contr.}$ = 1.80; F = 5.837, Sig. = .26) and Level 4 (M_{map} = 0.88; $M_{contr.}$ = 3.51; F = 11.610, Sig. = .003). Students in mapping groups tend to construct the problem space in several problem clusters that is shown by the greater number of nodes at Level 1 and to present at Level 2 the most of the concepts. The Levels 3, 4 and 5 show relatively lower number of concepts. The fact that most concepts are distributed at level 2 and level 1 could be interpreted in terms of concepts’ importance for the problem. It is supposed that the closer a concept is to the central idea the higher are its importance and significance for the understanding and capturing the problem. Students from the control group produce maps with relatively equal distribution of concepts on level 1



to 4. Their maps are more linear. It could be concluded that for them it is more difficult to capture and keep in mind the complexity of the problem space.

Fig. 2*: Effect of Concept Mapping on Individual Fluency and Flexibility*

Enrichment, Knowledge Acquisition and Retention

Mapping groups score higher than control groups on enrichment criterion as the difference is near to the significant (M_{map} = 12.53; $M_{contr.}$ = 1.50; F = 3.707, Sig. = .069). Enrichment is caused by two opposite options: acquiring and incorporating in the cognitive structure new concepts (Knowledge Acquisition) and reduction or exclusion of concepts (Retention).

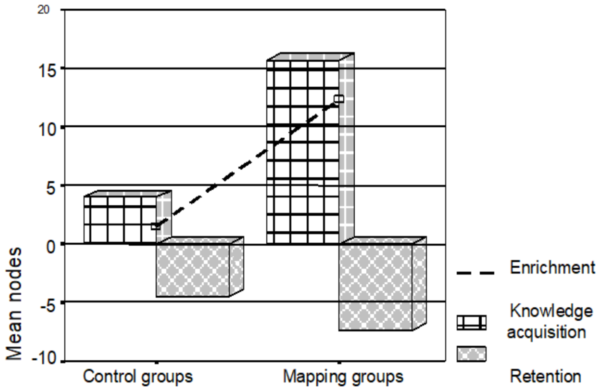


Fig.3*: Effect of Concept Mapping on Enrichment, Knowledge Acquisition and Retention*

The use of concept mapping shows to be predictive for the new knowledge acquisition and incorporation in the cognitive structure. Mapping students include much more new concepts in their post-test than students of the control groups (M_{map} = 15.71; $M_{contr.}$ = 4.00; F = 4.457, Sig. = .048).

The process of retention shows no significant difference. The expectation that because of its re-constructive power mapping approach should influence the personal autonomy, and hence the retention process, quite stronger, is not confirmed. A possible explanation is that the use of mapping representation frees some memory space and students do not need to reduce some concepts in order to incorporate new ones.

On the criteria of individual creativity and reconfiguration no significant difference was found. Our assumption that the use of concept mapping will provoke in general a high opportunity for individual patterns breaking is not confirmed. It should be mentioned here that the results of the control groups that have used a Brainstorming method, recognised as highly beneficial for creativity, are compared with the results of all mapping groups using different methods of collaboration.

Learning effectiveness as an interaction between individual students and the group

Probably the most interesting criteria for predictive power of concept mapping for the learning effectiveness in collaborative learning are the interaction between group work and individual cognitive reconstruction:

- Individual-to-group transfer, that show a difference near to the significant in favour of mapping groups (M_{map} = 11.47; $M_{contr.}$ = 4.50; F = 4.312, Sig. = .052), and
- Group-to-individual transfer, that is significantly higher for mapping groups (M_{map} = 19.71; $M_{contr.}$ = 5.50; F = 3.827, Sig. = .047)

One of the main challenging aspects of collaborative learning is to find an efficient way to elicit individual knowledge in collaborating groups and to communicate them. According the results of this study concept mapping is an effective tool for eliciting, representing and communicating knowledge in collaboration in a way that is meaningful and beneficial for all participants.

It could be summarised that concept mapping as a mediating tool is beneficial for group collaborative learning both at group and at individual level. It promotes establishing a common reference structure that is a basis for building shared group cognition. The use of concept mapping makes individual knowledge more explicit and more meaningful for other group members. They could be easier communicated, reflected and elaborated and then easier incorporated in individual cognition. In collaborative settings concept mapping is predictive for a conceptual change and cognitive reconstruction, for acquiring concepts and incorporating them in the existing cognitive structure as well as for the reconstruction of the cognition.

5. Mode of CM mediated group interaction as a predictor of learning effectiveness

Individual learning effectiveness

In general the experimental results show that the mode of interaction is strongly predictable for the individual learning effectiveness of collaborative problem solving, revealing the priority of 'Shared' mode of interaction in exploring the problem space.

Fluency and Flexibility

The mode of group interaction influences significantly the concepts fluency (F = 3.827, Sig. = .047) and links fluency (F = 3.797, Sig. = .048).

The precise distribution of results between groups reveal a priority of 'Shared' groups, followed by the 'Moderated' groups and the 'Distributed' groups. A post-hoc analysis by Bonferroni multiple comparison shows that the difference is significant between 'Shared' and 'Distributed' groups (MD = 19.25, Sig. = .046).

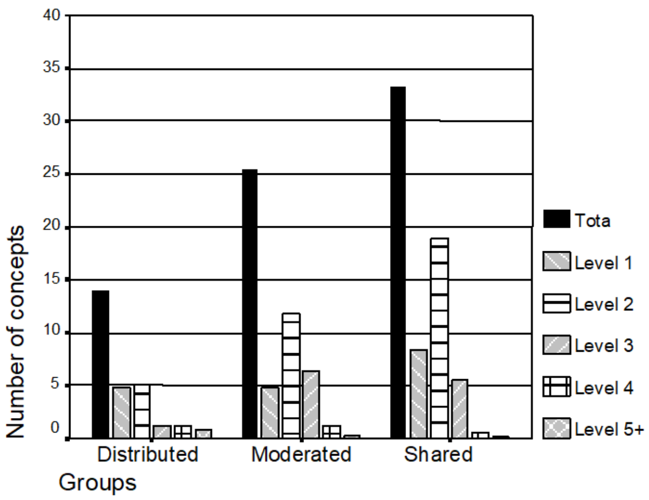


Fig.4: *Effect of the Mode of Group Interaction on the Individual Fluency and Flexibility*

Distribution of the nodes on concept levels shows that the main difference is caused by variance on conceptual level 2 as the difference here is near to the significant (F = 3.394, Sig. = .063). This suggests that the broadness of students' perception is caused not just by extension of the problem presentation beyond the task or by adding details. A possible perspective of interpretation is that the differences in conceptual fluency caused by the mode of group interaction is meaningful as far as they concern mainly the most central aspects of the task.

A multiple comparison analysis reveals again that the difference is more significant between Shared and Distributed groups (MD = 14.00, Sig. = .069) and the Moderated groups have a middle position.

Enrichment, Knowledge Acquisition and Retention

The conclusion that the Shared mode of interaction is the most beneficial is supported also by the data of criteria for students' knowledge enrichment. A comparison between post-test and pre-test knowledge shows a marginal significance in the growth of the cognitive picture on the task (F=3.126, Sig. = .075). The difference is more significant between 'Sharing' and 'Distributing' students (MD = 14.63, Sig. = .087) as the 'Moderated' students take the middle position.

The mode of group interaction shows to be strongly beneficial for incorporating new knowledge in the students' cognition. The difference of acquired new knowledge between groups is significant (F = 3.905, Sig. = .045) showing the priority of Shared mode against the Distributed mode (MD = 15.63, Sig. = .047). Students working in 'Moderated' mode also incorporated less new concepts in their personal cognitive structure than students in 'Shared' mode. An additional qualitative analysis shows that only those aspects of the group solution that were developed by the personal participation of a particular student were internalised in his/her cognition.

Students in 'Distributed' mode had a broad access to all other students' knowledge representation. But they were not able to gain from the externalised and represented in maps experience of the others as

much as even students in ‘Moderated’ mode, which could not use all other group members’ concept maps as distributed resources.
A possible explanation is that the Shared mode of interaction supports a deep understanding of knowledge. The Shared collaboration benefits because it is based on knowledge in action rather than because it provides a direct access to all group members’ representations. It leads to making the articulated concepts meaningful for all collaborators that is a prerequisite for incorporation of the new concepts in the existing cognitive structure. It could be concluded that the mode of sharing and the form of knowledge, which students communicate are more important than the access to the distributed resources itself.
The process of retention shows no significant difference, although it should be mentioned that students in Distributed mode reduced fewest concepts from their initial vision of the problem.

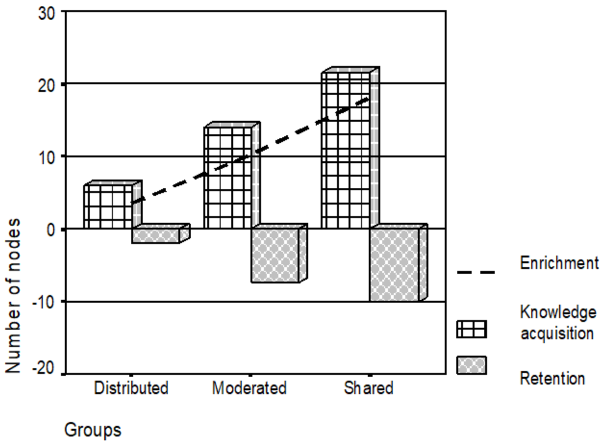


Fig. 5: *Effect of the Mode of Group Interaction on the Individual Enrichment, Knowledge Acquisition and Retention*

On criterion of formal reconfiguration (movement of the concepts between levels) no significant difference was found. An informal look trough the produced maps reveals that both the ‘Shared’ and ‘Moderated’ mode proved their potential for reconstruction of the individual cognition represented mainly by reshaping of map spatial configuration. Interdependence between spatial configuration of the common group problem solution and the individual outputs is found. The most of the students working within ‘Distributed’ mode resist on their prior map spatial configuration.

Surprisingly, the individual creativity is not influenced by the mode of group interaction. No significant difference is found.

Group effectiveness

The analysis of group learning effectiveness as expected shows a priority of the Shared mode of interaction on the criteria of concepts and links fluency as well as on criterion of group creativity.

Fluency and Flexibility
As expected the data indicate a great difference in the acquired knowledge especially between Shared and the other two types of groups. The broadness of the group vision about the problem is strongly influenced by the mode of interaction.
Surprisingly the Moderated groups score on criterion of concept fluency higher than Distributed groups. It was assumed that the opportunity to review all members’ individual maps as an access to considerable amount of distributed cognitive resources should influence positively the broadness of group problem solution. In fact the way and the form in which individual cognitive resources are represented and manipulated in the group interaction is a stronger factor of group learning effectiveness than the amount of distributed resources to which students have an access and how direct this access is.

Creativity
The superiority that Sharing mode shows on this criterion should be expected, moreover it is based on some features of brainstorming method that has proved its creative power.
Comparing the results on criteria of fluency and creativity it become clear that the main source of the differences between group results is the ideas generating process during the group session rather than the incorporation of the group members’ prior knowledge.

Learning effectiveness as an interaction between individual students and the group

The data analysis shows that the mode of interaction itself do not influence the process of eliciting individual knowledge in group collaboration and their incorporation in the group final output. No significant difference was found on the criterion of individual-to-group transfer. All three scenarios enabled students to present and incorporate their knowledge in the group process.

On criterion of group to individual transfer a strong significant difference was found (F = 13.843, Sig. = .000) On this criterion students in 'Shared' groups score significantly higher than students both in 'Moderated' (MD = 9.35, Sig. = .010) and 'Distributed' (MD = 14.00, Sig. = .001) groups. A significant number of the knowledge that is elaborated in the Shared session is incorporated as a meaningful part of students' cognitive structures and is transferred to individual cognitions.

Comparing the predictive power of the mode of interaction for the group learning effectiveness and the individual learning effectiveness it is obvious that Sharing mode is the most beneficial for the both of them. It could be expected that there is interdependence between group and individual leaning effectiveness and that the more successful groups are more beneficial for their members as individuals.

6. Summary and further perspectives

In summary, the experiment reveals that the learning effectiveness is influenced significantly by the mode of group interaction. In general, Shared interaction scenario proved to be the most effective in collaborative learning and problem solving. These leads to the conclusion that the learning effectiveness depends on the extend to which students share their learning not only as results but also as a process of knowledge acquisition and creation by a direct interaction. Experimentally validated Shared interaction scenario could be implemented in constructing collaborative learning environment. From the perspective of computer supported collaborative learning Shared mode has a limitation that it could be used only in synchronous settings. The next step probably is to find precisely which are the most distinctive features of this mode of concept mapping mediated collaboration and how they could be incorporated or/and compensated in the conditions of asynchronous collaboration.

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