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FOSTERING COLLABORATIVE KNOWLEDGE CONSTRUCTION WITH VISUALIZATION TOOLS

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Abstract

This study investigates to what extent collaborative knowledge construction can be fostered by providing students with visualization tools as structural support. Thirty-two students of Educational Psychology took part in the study. The students were subdivided into dyads and asked to solve a case problem of their learning domain under one of two conditions: 1) with content-specific visualization 2) with content-unspecific visualization. Results show that by being provided with a content-specific visualization tool, both the process and the outcome of the cooperative effort improved. More specifically, dyads under that condition referred to more adequate concepts, risked more conflicts, and were more successful in integrating prior knowledge into the collaborative solution. Moreover, those learning partners had a more similar individual learning outcome.

In recent years, many research activities have been directed towards analyzing discourse in cooperative learning (e. g. Dillenbourg, 1999; Mason, 1998; Kumpulainen & Mutanen, 1999). Today, we know more about discourse aspects contributing to improved learning outcomes. Scientific knowledge on processes of collaborative knowledge construction helps us to support learners more effectively in situations of collaborative learning. Recent instructional approaches include socio-cognitive structuring (e. g. O' Donnell & King, 1999) as well as shared representation or visualization techniques for fostering cooperative learning. In this paper we present findings from a study on supporting the collaborative knowledge construction with two different kinds of visualization tools.

Processes of collaborative knowledge construction and cooperative learning outcomes

Knowledge construction as process. "Co-construction of knowledge", "collaborative knowledge-construction", and "reciprocal sense-making" are examples of terms commonly used in research to describe the cognitive processes relevant to cooperative learning (Dillenbourg, Baker, Blaye & O' Malley, 1995; Nastasi & Clements, 1992; Roschelle & Teasley, 1995): In theoretical and empirical papers the description or analysis of collaborative knowledge construction is often approached through the aspects of content and function of discourse. Regarding content-related aspects, a central question is to what extent, how frequently, and how adequately learners talk about the specific content of the learning task? So far, most studies have focussed on the way learners cooperatively process the content – hence, the functions of utterances in discourse are taken into consideration. For example, Renkl (1997) analyzed questions and follow-up questions in discourse, whereas Nastasi and

Clements (1992) concluded in their research that rejection of suggestions are indicators of cognitive conflicts. Until now there has been a lack of empirical approaches which give equal weight to qualitative content-related and functional aspects. On the basis of the existing literature we distinguish four processes of collaborative knowledge construction which cover a content perspective as well as a functional perspective: (1) Externalization of task-relevant knowledge, (2) elicitation of task-relevant knowledge, (3) conflict-oriented consensus building and (4) integration-oriented consensus building. These will be described below.

Externalization of task-relevant knowledge. A necessary condition for the collaborative construction of knowledge in discourse is that learners bring individual prior knowledge into the situation; only then differing views and opinions can be clarified. Especially, approaches of situated learning attach relevance to externalization, because they consider the exchange of different individual concepts to be the starting point for the negotiation of common meaning in discourse (Brown, Collins & Duguid, 1989). Also, theoretical and empirical studies generally highlight the fact that externalization is an important requirement for the "diagnosis and therapy" of misconceptions (Schnotz, 1998).

(2) Elicitation of task-relevant knowledge. A further important aspect of collaborative knowledge construction is causing the learning partner to express knowledge related to the task. This is sometimes referred to as 'using the learning partner as a resource' (Dillenbourg et al., 1995). It is plausible to assume that elicitations (frequently in form of "questions") lead to

externalizations, often in the form of explanations. Therefore, elicitations could be partly responsible for successful learning (e.g. King, 1994).

(3) Conflict-oriented consensus building. Cooperative learning often causes learners to come to a common solution or assessment of the given facts. This necessary consensus can be reached in different ways. In the literature on cooperative learning socio-cognitive conflict plays an important role (Doise & Mugny, 1984; Nastasi & Clements, 1992; see Dillenbourg, 1999): It is assumed that the different interpretations made by learning partners stimulate processes which can lead to a modification of knowledge structures.

(4) Integration-Oriented Consensus Building. Another way to reach consensus is to integrate the varying individual perspectives into a common interpretation or solution of the given task. This form of consensus building may be important under some conditions. However, the attempt to incorporate all individual views in a common perspective may also lead to a superficial conflict-avoiding cooperation style. The phenomenon that learners, despite drastically differing views from an objective perspective, claim that they are basically in agreement, has been observed many times (Christensen & Larson, 1993; Miyake, 1986; Hatano & Inagaki, 1991). One could speak of a tendency on the part of the learners to reach an illusionary consensus.

In this study we examine, to what extent these processes can be facilitated by instructional means. We approach the measurement of these processes with combined analyses of the content and the functional level of discourse.

Cooperative learning outcome. In research on cooperative learning there are different ideas about what is to be understood as a successful learning outcome (see Salomon & Perkins, 1998). Usually, the conditions of individual achievement are given most consideration . However, other approaches see learning as a process substantially influenced by the entire context. In this view, learning should therefore only be analyzed by taking account of the whole context (e.g. Scardamalia & Bereiter, 1994). The quality and breadth of individual knowledge construction is often given little attention in comparison to the analysis of the co-construction of knowledge in a given context. In many educational settings, it makes little sense to completely neglect the individual learning outcome, especially if not only communication and cooperation competencies are being aimed at, but also individual knowledge and skills.

A second question is to what extent the individual learning partners, through cooperation, acquire similar knowledge on a subject matter. Concerning this issue, it is considered important in theoretical and empirical studies that learners negotiate a common solution, manage socio-cognitive conflicts etc. So far, however, questions about the degree in which individuals benefit differently from cooperation have seldom been raised. Does everyone learn the same amount and the same content (e. g. Cohen & Lotan, 1995)? Or does everybody learn the same amount, but in different domains, as envisioned by the concept of distributed expertise (Brown, Ash, Rutherford, Nakagawa, Gordon & Campione, 1993)? Could it possibly happen, that learners benefit from the knowledge and skill of others, without however being of any profit to learning partners? Such, usually undesirable, effects of divergence between the learning outcomes of learning partners are interestingly not covered in many theoretical approaches to cooperative learning.

On this background we include in our study collaborative outcome measures as well as the group-to-individual transfer. Moreover, we consider intra-dyadic divergence effects.

Fostering Collaborative Construction of Knowledge with Visualization Techniques

An array of studies to cooperative learning has shown that efficient learning is rarely achieved solely by bringing learners together. In order for the discourse to attain a certain depth, learners usually require supportive instruction. Different forms of support for the collaborative construction of knowledge have been developed and evaluated. They often include scenarios, scripts or roles. Interestingly, most approaches are content-unspecific, i. e. they include formalisms which do not take the content of the learning environment into consideration. Through the designation of typical roles, interactive processes such as explaining and questioning are encouraged which are relevant to a vast field of content. With the goal of fostering text comprehension, reciprocal teaching is an example of content unspecific support in cooperative learning (Hart & Speece, 1998; Palincsar & Brown, 1984). This method uses the roles of 'teacher' and 'student' and can be used for supporting reading comprehension in virtually any domain. On the other hand, a more content-specific structuring method supports the learning partners in the qualitative processing of the task. In that respect, the learning partners are for example provided with an abstract diagram of the task, or a visualization of central, yet abstract characteristics of the task. In our study a content-specific visualization based on mapping techniques was used to facilitate the collaborative construction of knowledge. The basic principle of mapping techniques (e. g. concept mapping) is to visualize concepts (on index cards, for example) and to connect these concepts with appropriate relations. Working with such a technique results in a network (or map) of interrelated concepts. As such, a mapping technique is content-unspecific as well. However, one of the main advantages of mapping techniques for the use in cooperative learning is their adaptability to specific content. With certain types (or categories) of index cards and certain types of relations, important abstract concepts are provided that can help focus the learners' discourse on relevant aspects without undue constraint.

In their content-unspecific versions mapping techniques have already proven to be effective in supporting processes of individual knowledge construction (see Jonassen, Beissner & Yacci, 1993). In particular, the acquisition of conceptual knowledge in fields like science education or preservice teacher education has been shown to benefit from mapping techniques (e. g. Beyerbach & Smith, 1990; Novak, 1998; Novak & Musonda, 1991). However, self-constructed maps proved to be more efficient than pre-made ones (McCagg & Dansereau, 1991). Furthermore, studies have shown that mapping techniques can, under certain conditions, also support the application of knowledge in learning with cases (e. g. Fischer et al., 1996; Mandl, Gräsel & Fischer, 2000). For several years, concept mapping has been implemented to foster cooperative learning (e. g. Plötzner, Fehse, Kneser & Spada, 1999). Initial investigations on concept mapping in cooperative learning environments indicate that it can foster a more intensive discourse between learners (Roth & Roychoudhury, 1993; van Boxtel, van der Linden &

Kanselaar, 1997). In a pilot study from Suthers (2000) the use of a graphic mapping tool proved to be more capable of supporting cooperative learning than the textual representation. Moreover, a study by Roth (1994) showed that students emphasize the usefulness of collaborative concept mapping as a learning tool.

But how can a content-specific mapping tool promote collaborative knowledge construction? We suppose that task-relevant externalization and in particular the externalization of abstract concepts as well as relations between concepts can be promoted with a content-specific mapping tool. Such a tool provides both particular categories (types of index cards) and particular relations; thus, discourse can be focused on these predicates (Collins & Brown, 1988). For example, it can be expected that collaborating on a complex problem with a mapping tool that provides the categories theoretical concept and case information will help the learner to distinguish given information or observation from interpretation on the basis of theoretical knowledge. Lacking this support, learners might use everyday concepts for the solution of a problem, without differentiating between given case information and their own interpretation. The pilot study from Suthers (2000) demonstrated that learners working collaboratively on a so called science challenge with the support of a content-specific mapping tool externalized a higher number of evidence relations than learners who where only provided with a text tool.

Furthermore, a pre-structured mapping tool can help to detect missing explanations in the learners' representation: It can be seen at a glance whether a concept was used in the map, which could not be related with other cards. These "loose ends" can, then, lead to an elicitation of knowledge; a learning partner may happen to know a possible interpretation of a so far isolated piece of information. Two problems can arise when trying to find an adequate consensus while collaboratively solving problems. The most obvious, is that learners cannot agree on a common solution. Another possible problem is that an agreement is reached which is inadequate, because the learners have reached an illusionary consensus: Positions are taken as being mostly the same even though they are not. This may be led back to two sorts of causes: cognitive and discoursive causes on the one hand as well as emotional and motivational ones on the other hand (Christensen & Larson, 1993; Fischer & Mandl, in press). Due to cognitive and discoursive causes, the differentiation of positions held in the discussion may become more difficult to detect, for example, through a too high level of ambiguity of a claim or the lack of cognitive prerequisites (e. g. prior knowledge). If, besides that, learning partners are not motivated to cooperate, then the discourse will be held with the least possible effort (e. g. Webb, 1989). Potential conflicts will therefore be avoided.

With content-specific visualization on the basis of a mapping technique, the cognitive and discoursive causes of the illusionary consensus become more apparent. We suppose that by representing the concepts and relations with the mapping technique, the ambiguity of utterances can be reduced. Differing views can be detected more easily. This possibly leads to cognitive conflict and to the negotiation of meaning - both of which can be assumed to improve the learning outcome (Nastasi & Clements, 1992; Roth & Roychoudhury, 1993).

To sum up, we expect positive effects of content-specific visualization on the basis of mapping techniques on the collaborative construction of knowledge.

On this background we will examine the following research questions:

(1) To what extent can processes of collaborative knowledge construction be supported by content-specific visualization?

(2) To what extent can the cooperative learning outcome be improved with content-specific visualization?

(3) To what extent does content-specific visualization influence

(a) the group-to-individual transfer and

(b) the intra-dyadic divergence of learning partners in the group-to-individual transfer?

Method

Participants. Thirty-two students of Educational Psychology in their 3rd to 5th semester at the University of Munich took part in this study. The participants were subdivided into dyads minding that the partners were only acquainted with each other through their studies. In particular, we made sure that partners had not previously worked together in groups. Each dyad was randomly assigned to one of the two experimental conditions.

Design and course of the study. First, the participants were introduced extensively to the cooperative learning environment. After this they worked cooperatively on three complex learning tasks (cases) in written form. The content of the cases dealt with the design of learning environments from the viewpoint of theories of motivation. Specifically, the task of the learners was to advise fictitious instructors (e.g. school teachers or adult educators) on a draft of a specific lesson that they (the instructors) were to give. More specifically, the participants' were to collaboratively prepare a final evaluation of the planned lesson based on concepts drawn from motivation theories. For this purpose they were provided with a text that explained central theoretical concepts. More specifically, we asked the learners to evaluate the proposed lecture plan by using theoretical concepts (e. g. from the theoretical text or from their prior studies). Both learners got a print-out of the case text and were asked to come to a consensus concerning the evaluation of the case. Moreover, they were asked to use the graphic tool to represent their solution and - in doing this - prepare a final oral evaluation.

Two different kinds of visualization were compared: (1) Content-specific visualization. For this condition we developed a computer-based mapping technique called "CoStructure-Tool". The tool presents a kind of reification of central elements of the task structure: The CoStructure-Tool's graphical user interface is divided into two conceptual planes labeled "theoretical" and "empirical". In a theoretical plane two types of 'boxes' were available: One in which the participants could enter the theoretical concept which they considered to be accomplished in the lesson. The other type contained the specific defining conditions of the theoretical concept. The empirical plane contained boxes in which the learners could enter information from the case that seemed relevant to them. In addition to the boxes, two types of relations were provided for positive and negative connections between concepts. Connections were possible between boxes of any type. Theory boxes, for example, could be connected with each other as well as with case information. The size and position of both the boxes and their relations could be manipulated on the screen. All of the tool's functionality was accessible via direct manipulation (i. e. no pull-down or pop-up menus were used). In pilot studies the CoStructure-Tool proved to be easy to learn and handle. (2) Content-unspecific visualization (control). The learners in the control group used a graphic editor of the kind that is widespread as shared whiteboard in computer environments (e. g. Dillenbourg & Traum, 1997). The functionality of this tool is available on a toolbar and includes a text-editor, creation of rectangles, circles and lines, as well as freehand drawing with the mouse. All objects can be freely moved and filled with a color of choice. As with the content-specific tool, all of the tool's functionality was accessible by direct manipulation of the objects on the screen.

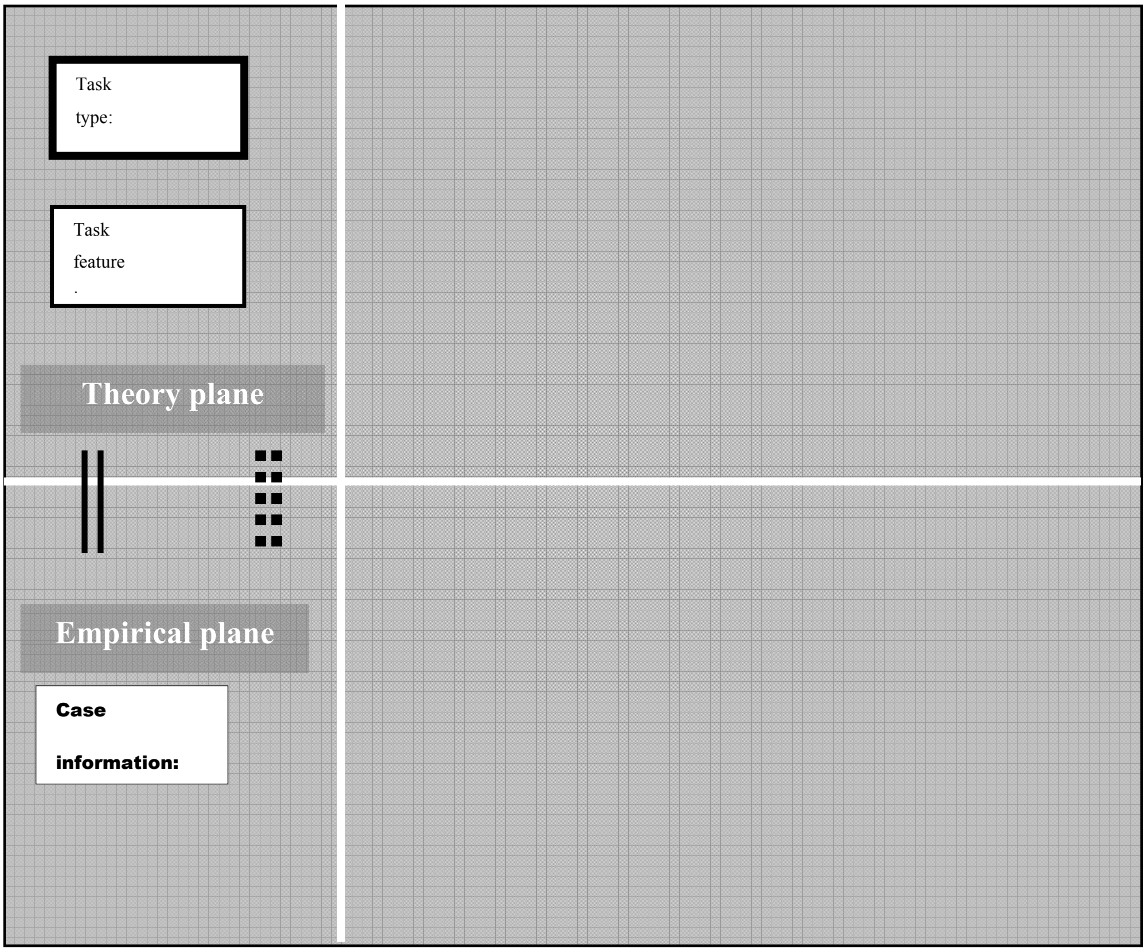

Fig. 1. The content-specific visualization tool (CoStructure-Tool). The screen is devided into two planes: the empirical and the theoretical plane. On the theoretical plane two different types of boxes are provided (for “task type” and “task feature”). On the empirical plane “case information” boxes are available. With the different kinds of relations (straight lines for positive relation and dotted lines for negative ones) all three types of boxes can be connected.

Thus, in contrast to the content-specific visualization, neither different conceptual planes, nor the concept cards, nor their semantic labels, nor any connection type could be found in the learning environment. However, compared to the content-specific visualization, the content-unspecific visualization enables students to express their thoughts with less constraints.
We used this condition to control for possible supporting effects of the external representation, e. g. the reduction of cognitive load through note-taking or visualizing (Fisher, 1990).

Apart from the instructions stated above and the tool constraints, no further structure was imposed on the dyads. Learners did not have to handle pull-down or pop-up menus.

Measurement of collaborative construction of knowledge. The participants' discourse during their work on the second case was recorded on tape. The transcriptions from the tapes formed the data basis of the measured dependent variables. They were segmented by trained evaluators into approx. 4000 speech acts and analyzed with a coding system (Bruhn, Gräsel, Fischer & Mandl, 1997). With the help of this instrument, each utterance can be analyzed simultaneously on the levels "content" and "communicative function". The function categories are based on a speech-act-oriented coding system for the analysis of colloquial speech (e.g. Thomas, Bull & Roger, 1982).

Before and after the cooperation phase, the participants worked on an individual knowledge test. Both tests contained a short version of the same theme that was dealt with during the cooperation phase. Learners were given ten minutes and were asked to use theoretical concepts when working with the short version. Also, they were asked to speak out loud. The think-aloud process had been practiced previously on a case example from a different domain. In a last step, the learners gave a final oral evaluation of the case, which was recorded on tape.

Measurement

Content of the Collaborative Construction of Knowledge. First, the distinction between on-content and other content was made.

On content. This included all theoretical concepts and the case information mentioned in relation to the task, as well as their interrelations, regardless of whether they were mentioned literally or paraphrased. (1) Theoretical concepts. This category was chosen when an utterance included a theoretical concept from the theoretical text or from the speaker's own prior knowledge ("Extrinsic motivation is when you're rewarded"). (2) Case information. This category consists of all content found in the case regardless of whether it was relevant to its solution ("So, they get to see a video at the end as a reward"). (3) Relation between case information and theoretical concept. This category was used when subjects related theoretical concepts to information from the case ("This bonus for the best, that's definitely an extrinsic motivation").

Other content. This included all off-task content ("Did you watch the news last night?") as well as operational coordination ("Can you let me move that alone, for once?"; see section Control Measures).

After an aprox. 10-hour training, a very good inter-rater reliability was achieved (Cohen's Kappa = .85).

Processes of Collaborative Construction of Knowledge

We assessed the processes of collaborative construction of knowledge (externalization, elicitation, integration-oriented and conflict-oriented consensus building) through a combined analysis of the content level and functional level. Regarding the content level, only on-task utterances were given consideration for these processes. Then we analyzed the utterances as to which communicative functions were used. Here, we used the coding scheme from Thomas et al. (1982), that is claimed to be high in reliability. (1) Statements. Statements are utterances with the function of imparting information to the learning partner ("So, first we have the teacher, and then also these external experts"). (2) Request for information. This category is used when the speaker requests a piece of information from the partner ("How many students were in the previous example?"). (3) Give requested information. An utterance which contains only requested information ("Twelve students!"). (4) Suggestions. The speaker suggests something he or the listener or both could do ("Well, we could say that this reward inhibits intrinsic motivation"). (5) Agreement. Agreement is when there is an accepting or positive evaluation of a prior utterance (not necessarily a suggestion) ("Okay, you're probably right with that reward stuff"). (6) Rejection. A rejection is a negative evaluation of a prior utterance (not necessarily a suggestion) ("I don't think so, since that's rather just an additional motivation"). (7) Commissives. Commissives are utterances in which the speaker announces, promises or threatens to do something that may or may not include the listener ("We'll just agree on the definition written there"). (8) Directives. Directives are utterances in which the speaker asks, orders or instructs the listener to do (or not to do) something ("Go, get the article, so we can look it up").After an approx. ten-hour training, a very good inter-rater reliability was achieved for this coding scheme as well (Cohen's Kappa = .80).

On the basis of the content scoring and the functional classification of the speech acts we determined the four processes of collaborative construction of knowledge (i. e. as a combined analysis of content and communicative function) as follows. The utterances listed under the explanation of communicative function can serve as examples, since this selection consists exclusively of on-task content: (1) Externalization. Utterances with on-task content and the functions "statement", "give requested information", "suggestion", or "commissive" were categorized as externalization. (2) Elicitation. An utterance with on-task content and the communicative function "request for information" or "directive" was categorized as elicitation. (3) Integration-oriented consensus building. Agreements with on-task content were categorized as integration-oriented consensus building. (4) Conflict-oriented consensus building. Rejections of on-task content were categorized as conflict-oriented consensus building.

Collaborative Outcomes

Two different measures were chosen as indicators of collaborative outcomes. The first measure is based on the final spoken evaluation of the case, the other is based on the graphical representation.

(1) Appropriate use of theoretical concepts. To assess the appropriate use of theoretical concepts quantitatively we measured (a) the application of prior-knowledge concepts. For this measure we determined the number of theoretical concepts stemming from the participants' prior knowledge which they used appropriately in the final evaluation. Appropriate prior knowledge concepts were defined as those theoretical concepts which, though relevant for the task, were not found in the learning environment (i.e. in the theory text). (b) Moreover, we assessed the application of theoretical concepts given in the learning environment. Here, we determined the number of appropriately used theoretical concepts that could be taken from the theory text in the final task evaluation.

(2) Quality of the collaborative problem solution. On the basis of the graphical representation we determined the quality of the collaborative solution to the task problem. Two experts assessed the graphical solutions according to four levels of solution quality: (a) Low solution quality. The graphical solution only contains everyday concepts and case information. The representation of the case is inadequate. Weak points in the case are hardly or not at all discovered . (b) Rather low solution quality. Some theoretical concepts are integrated in a set of everyday concepts. Only some parts of the representation of the case are adequate. Weak points in the case are hardly or not at all discovered. (c) Rather high solution quality. The representation of the case is

adequate. Weak points in the case are partly discovered. (d) High solution quality. The representation of the case is adequate. Almost all or all weak points in the case are discovered.

Group-to-individual transfer

(1) Individual transfer of knowledge. To determine the individual transfer of knowledge, the amount of adequately used theoretical concepts in the individual transfer exercise was determined. For this purpose the oral solutions of individual learners were compared with the solutions of a teaching expert. "Adequately used" means that (a) theoretical concepts are used, which the expert has equally used to work with the case (b) theoretical concepts are used with a justification or are brought together with information from the case.

(2) Intragroup divergence of group-to-individual transfer. As an indicator of the intradyadic divergence we used the positive numerical difference from the group mean (i. e. the halved positive difference between the two dyadic values) for the variable of individual transfer of knowledge.

Control Measures

The following variables were included in the analyses as controls: (a) Preference of collaborative learning (scales for the preference of collaborative and competitive learning from Neber, 1994). This was measured to control uneven distribution of these preferences with respect to the treatment groups. (b) Operational coordination. With this measure, determined from the discourse transcripts, we checked whether the differences in using the hardware and software in the learning environment could itself lead to differences between the two groups. This category consisted of utterances in which the partners coordinated their activities regarding the operation of the learning environment, for example the manipulation of the mouse or keyboard ("do you want to type that, or should I?") or the manipulation of objects on the screen ("and how do you get that box up there again?"). (c) Acceptance of the learning environment and motivational effects. At the end of the experiment, certain subjective variables were measured with a computer-based questionnaire. The acceptance of the learning environment was measured individually with the item "I would appreciate a more frequent use of similar learning environments in my university education". Possible effects of the learning environment on the motivation of learners were measured with a five items scale (including items like for example "I enjoyed to work collaboratively on the cases").

Unit of analysis. One of the methodological problems of empirical investigation of collaborative learning is the question of whether the unit of analysis should be the individual or the group. We used the dyads as the unit of analysis for the research questions 1 and 2 which are directed to the discourse and at the collaborative solution of the task as the learning outcome. The same unit of analysis was used in the context of the intradyadic divergence analysis in research question 3. In contrast, the individual as the unit of analysis was used to determine the individual transfer from collaborative knowledge construction according to research question 3.

In the statistical tests on mean differences, the alpha level of .05 was chosen. To test equal distribution of the control variables in both conditions the alpha level was set to .2.

Results

Learning requirements and control measures

There are no differences between the groups regarding preference for collaborative learning ($t(30) = -1.22$, $p > .20$). Time-on-task was held constant for all dyads. The two groups show no differences regarding the mean total number of utterances ($t(14) = 0.86$; $p > .20$). Furthermore, there are no differences between the two groups in the amount of verbal effort spent on operational coordination ($t(14) = -0.48$; $p > .20$). After the cooperation, the acceptance and motivation of learners was individually measured with a questionnaire. No differences could be found concerning the acceptance item ($t(30) = -1.22$; $p > .20$). The same is true for motivational effects of the learning environment ($t(14) = 0$; $p > .20$).

Results for Research Question 1

In this section we will first present the findings on the content of the knowledge construction. Then, we will describe the results for the processes of collaborative knowledge construction. These processes (externalization etc.) are derived from a combined analysis of the content and the functional level of discourse.

Content of the collaborative construction of knowledge

The two groups do not differ regarding "other content" utterances (Tab. 1). There are also no differences between the learners of each condition regarding how frequently case information was referred to.

Table 1

Means (standard deviations in parentheses) for the content of the collaborative knowledge construction in the two experimental conditions. Results of the t-tests (d = effect sizes).

	Content-specific visualization		Content-unspecific visualization				
	M	SD	M	SD	d	t *	p
On content							
Case Information	61.75	(43.37)	59.63	(42.91)	0.03	0.10	n.s.
Theoretical Concepts	17.63	(6.35)	3.75	(3.20)	2.91	5.52	< .05
Relations	42.25	(22.70)	26.25	(23.90)	0.69	1.37	< .10
Other content	119.63	(44.12)	119.75	(32.25)	0.00	-0.01	n.s.

* Note. t = t-value for df = 14 in the case of equal variances; else the degrees of freedom were adjusted.

There were, however, differences regarding the theoretical concepts. The group with the content-specific visualization tool had a significant advantage. This tendency is repeated regarding relations between theoretical concepts and case information. However, the effect size is smaller here than concerning theoretical concepts. The altogether greater number of on-task utterances in the group with the content-specific visualization tool can not merely be explained by more frequent mentioning or repetition of case information. Rather, this difference is attributable to a more frequent use of theoretical concepts and relations.

Processes of collaborative construction of knowledge

Regarding externalization (Table 2) there were also advantages for the learners with the content-specific visualization tool: Compared to the dyads in the control group, the dyads in the content-specific group tended to externalize more task-relevant knowledge and to elicit it more often from the learning partner.

Table 2
Means (standard deviations in parentheses) for the processes of collaborative construction of knowledge in the two experimental conditions. Results of the t-tests (d = effect sizes).

	Content-specific visualization		Content-unspecific visualization				
	M	SD	M	SD	d	t *	p
Externalization	102.00	(37.33)	76.88	(17.39)	0.92	1.73	< .10
Elicitation	15.13	(7.99)	10.25	(6.50)	0.67	1.34	< .10
Integration-oriented consensus building	20.38	(15.57)	15.38	(10.68)	0.38	0.75	n.s.
Conflict oriented consensus building	8.63	(5.32)	3.88	(2.53)	1.21	2.28	< .05

* Note. t = t-value for df = 14 in the case of equal variances; else the degrees of freedom were adjusted.

Learners with the content-specific visualization tool expressed more utterances of the type 'conflict-oriented consensus building'. Nevertheless, there were no substantial differences between the experimental conditions regarding integration-oriented consensus building.

To sum up the findings for research question one: The content-specific visualization tool influences the discourse of learners. In this condition, more on-task content is introduced (particularly theoretical concepts); regarding the processes of collaborative knowledge construction more conflict-oriented consensus building as well as a tendency to more externalization and elicitation of on-task knowledge were registered.

Results for question 2

Appropriate use of theoretical concepts. In both conditions the number of prior knowledge concepts declined significantly from the first collaborative case to the third one ($t(14) = 5.6$; $p < .01$). The number of "new" theoretical concepts, on the other hand, increased significantly ($t(14) = 8.95$; $p < .01$).

Differences between the two experimental groups were observed in their use of prior knowledge concepts in the collaborative solution of the last problem: The dyads who had taken part under the condition of a content-specific visualization tool contributed significantly more prior-knowledge concepts to their solution than the dyads in the control group. This difference did not prove to be significant concerning their use of theoretical concepts given in the learning environment.

Table 3
Means (standard deviations in parentheses) for the collaborative use of theoretical concepts in the two experimental conditions. Results of the t-tests. (d = effect sizes).

	Content-specific visualization		Content-unspecific visualization				
	M	SD	M	SD	d	t *	p
Use of prior knowledge concepts	1.00	(0.93)	0.25	(0.46)	1.08	2.05	< .05
Use of theoretical concepts given in the learning environment	6.50	(1.31)	5.75	(3.01)	0.35	0.65	n.s.

* Note. t = t-value for df = 14 in the case of equal variances; else the degrees of freedom were adjusted.

The dyads in both experimental conditions succeeded to a comparable quantitative degree in integrating theoretical concepts from a text in their solutions. Yet, in comparison with the content-unspecific tool, the content-specific visualization tool was of more help in applying theoretical concepts acquired earlier in their studies.

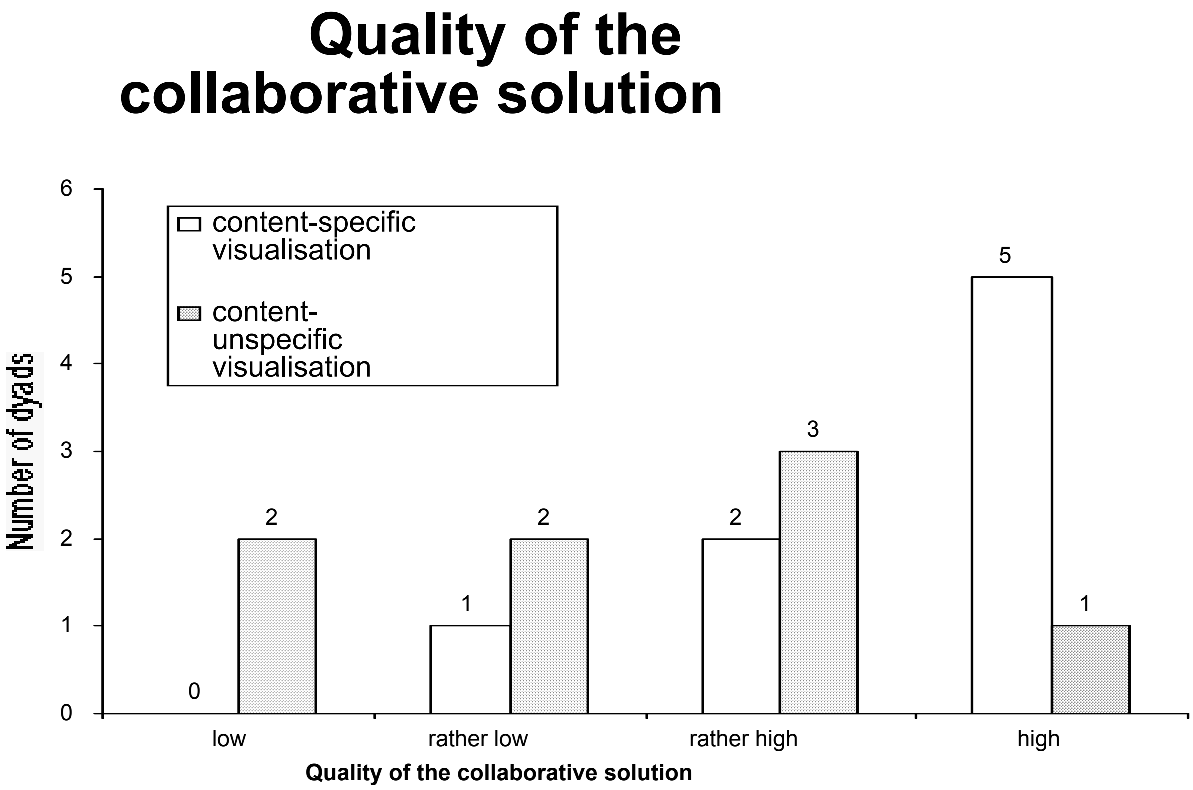

Figure 2: Quality of the collaborative solution. Frequencies for the four solution quality categories in the two experimental conditions.

Quality of the collaborative problem solution. Experts rated the graphical solutions with respect to their adequacy. Figure 3 shows the frequencies of the four categories for the experimental conditions. Whereas 4 of the 8 dyads with the content-unspecific visualization constructed graphical solutions of low or rather low quality, only one dyad with content-specific visualization could be categorized as such. In contrast, 5 of the 8 dyads in the content-specific condition constructed highly adequate solutions, whereas only one dyad in the control condition did. A comparison of mean ratings of the content-specific (m = 2.5, sd = 0,77) and the content-unspecific condition (m = 1.13, sd = 0,84) showed significant differences in favor of the former ($t(14) = 3.45$; $p < .05$).

Results for question 3

The group-to-individual transfer was determined by means of adequately used theoretical concepts in the individual short case pre- and post-test. Concerning post-test mean values, the results for the content-specific visualization dyads (m= 2.06, sd = 2.11) are slightly lower as compared to the control dyads (m = 2.68, sd = 2.72). The analysis of the repeated measurements including pre- and post-test scores showed that the number of adequately used theoretical concepts significantly increased from pre- to post-test under both of the conditions ($F\ (1,30) = 30.13$, $p < .05$). However, the conditions do not differ substantially regarding these changes ($F\ (1,30) < 1$, n. s.).

In contrast, the analysis of intra-dyadic divergence showed surprisingly clear differences between the conditions: If a content-specific visualization tool is used during the cooperation, the learning partners reach a more similar level of learning achievement (m = 0.81, sd = 1.41) than when working with a content-unspecific visualization tool (m = 2.38, sd = 0.99). This difference reached statistical significance in a two-tailed t-test ($t(14) = -2.56$; $p < .05$).

Discussion

The starting point of this study was the question of how collaborative construction of knowledge in cooperative learning can be fostered. With the content-specific visualization tool, a form of structured cooperative learning was implemented that represents a promising complement to the instructional methods employed thus far (e.g. Baker & Lund, 1997; Hron, Hesse, Reinhard & Picard, 1997; O'Donnell & Dansereau, 1992; Palincsar & Brown, 1984; see Slavin, 1996). The collaborative knowledge construction of dyads who had a content-specific visualization tool reached a substantially higher quality. The clearest effect in content was shown in the construction processes dealing with theoretical concepts. The dyads with the content-specific visualization tool were more inclined to integrate theoretical concepts into the solution of the problem. This effect is in line with other results of studies on the cooperative use of concept mapping (e. g. Roth & Roychoudhury, 1993): Structural support, such as concept mapping tools, can foster cognitive processes relevant for learning, (e. g. abstraction and organization processes). In our case, the differentiation between the empirical and theoretical levels on the screen of the tool may have additionally contributed to the significantly higher use of abstract theoretical concepts by the learners with the content-specific visualization tool. Theoretical arguments on the connection between abstraction and transfer (Oshima, Scardamalia & Bereiter, 1996; Schwartz, 1995) underscore the relevance of this effect.

Likewise, the findings on the processes of collaborative knowledge construction are indicators of the higher quality of discourse. The learners with the content-specific visualization tool externalize more on-task knowledge and show conflict-oriented consensus building regarding task-relevant content more frequently. The articulation of one's own perspective and the willingness to face socio-cognitive conflicts can be considered important conditions for conceptual change in cooperative learning (Nastasi & Clements, 1992; Schnotz, 1998). These findings can be seen as indicators for a higher level of discourse quality in the group with the content-specific visualization tool, because superficial cooperation is often connected with the avoidance of conflicts (Renkl & Mandl, 1995). By holding back one's own perspective, i.e. through reduced externalization of on-task knowledge, the risk of a conflict decreases (Christensen & Larson, 1993).

Regarding the quality of the collaborative solution of the task, the content-specific visualization tool promotes the use of theoretical prior-knowledge concepts. After working on three cases, the learners with that tool were better able to integrate concepts acquired in their studies along with newly acquired concepts. More importantly, the qualitative analyses of the problem solutions showed that with content-specific visualization the probability of an adequate solution increases. No dyad in this condition used a „naive model“ (a model with no theoretical concepts) to work on the case.

The comparison of group means showed no difference in knowledge gain under the two visualization conditions. However, the analysis of divergence showed that the conditions of individual learning outcome differ greatly in respect with another aspect: having worked with the content-specific visualization, the learning partners had more similar levels of individual transfer than with the content-unspecific visualization. The latter was often only of benefit to one of the two learning partners; the other was not capable of adequately applying knowledge. A possible explanation for this effect is that the content-specific pre-structuring represents a semantic coordinating element which helps learners by posing constraints in working on the case. An important difference between content-specific and content-unspecific visualization could therefore be seen in the fact that the former creates a content-specific structure in the form of a visual language (Gaßner, Tewissen, Mühlenbrock, Loesch & Hoppe, 1998)), whereas the latter requires a negotiation of the meaning of the graphical elements. If this negotiation does not happen adequately, different individuals will benefit from this representation to various degrees. Moreover, the negotiated structure might be of help for the collaborative knowledge construction. However, less helpful graphical structures could be constructed as well. One can presume that the high popularity of graphical visualization for supporting cooperative learning processes (e.g. Schwartz, 1995), is founded mostly in the average learning outcome. Many of these techniques might promote highly diverging group-to-individual transfer for different members of the same group. Further empirical studies that analyze possible divergence effects of visualization tools, as well as possible divergence effects of scripts and other socio-cognitive structuring for cooperative learning (e. g. Palincsar & Brown, 1984), as well as newer developments for computer-supported and networked cooperative learning environments (e. g. Baker & Lund, 1997; Hron, Hesse, Reinhard & Picard, 1997) are necessary.

To sum up the interpretation of our findings thus far: The content-specific visualization encourages the learning partners' focus on the task-relevant content and increases the quality of the processes of collaborative knowledge construction, above all the application of abstract theoretical concepts. This fosters the quality of the collaborative solution to a problem case. Moreover, the content-specific visualization leads to more equal individual learning gains within the dyads.

Content-specific active visualization techniques like pre-structured mapping tools are an effective instructional support for collaborative knowledge construction - they can be implemented easily in computer-supported collaborative learning environments.

Keywords: Cooperative learning, discourse analysis, collaborative knowledge construction, collaborative concept mapping, collaborative learning.

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