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Computer support for knowledge construction in collaborative learning environments

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Abstract

Organisations increasingly use multidisciplinary teams to construct solutions for complex problems. Research has shown that multidisciplinary teams do not guarantee good problem solutions. Common ground is seen as vital to team performance. In this paper an ICT-tool to support complex problem solving is studied. A framework for knowledge construction inspired the design of computer support for knowledge construction. The basic support principle consisted of making individual perspectives explicit, which serves as a basis for negotiating common ground. This principle was embedded in a collaborative learning environment in three ways, which differed from each other in the extent to which users were coerced to adhere to the embedded support principles. Coercion, as expected, was correlated with negotiation of common ground; the more coercion, the more participants would negotiate the meaning of contributions to the ICT-tool, and the more common ground they would have. Self-report data suggested that Intermediate coercion resulted in the least common ground. This may have been caused by some disruption of group processes.

Keywords: Negotiation; Common ground; ICT-tools; Knowledge construction; Coercion

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1. Computer support for knowledge construction in collaborative learning environments

Multidisciplinary teams are used in industry, government and education (Derry, Adams DuRussel, & O'Donnell, 1998) because they are regarded as a sine qua non for solving complex problems (Vennix, 1996). The main advantage of multidisciplinary teams is that the team members can bring different perspectives to bear on a problem. Multiple perspectives are expected, for example, to allow for rich problem analyses and solutions (see Lomi, Larsen, & Ginsberg, 1997). Courtney (2001) argues that business organisations need to integrate different perspectives to ensure organisational sustainability. Hasan and Gould (2001) showed that ignoring certain perspectives on a complex problem can lead to unexpected adverse effects of the ultimate problem solution. And finally, Vennix (1996) notes that, "differences of viewpoint can be very productive" (p. 1). However, multidisciplinarity is not always an advantage. Sometimes individuals outperform multidisciplinary teams, even when it concerns the task of complex problem solving (Barron, 2003). The question is thus: What makes a multidisciplinary team successful?

Recent research by Barron (2003) in the domain of education empirically confirms the need for cognitive frames of reference. She showed that team performance is related to team interaction. She noted that the willingness to construct a shared problem space seemed to be essential for engaging multiple perspectives. High performing teams engaged solution proposals through discussion and acceptance, whereas low performing teams ignored and rejected proposals. According to Johnson and Johnson (1994), synthesis of multiple perspectives might result in better decisions and solutions to complex problems. Bromme (2000) argues that a team needs some *common ground*, a shared cognitive frame of reference, before it can attempt to synthesise perspectives. It seems that members of multidisciplinary teams need to find some kind of commonality between their different perspectives in order to benefit from them.

Many researchers have used ICT-tools to facilitate complex problem solving in teams. These tools use *formalisms,* which are constraints that structure conversation and discourse among collaborators with the aim to guide the exchange of knowledge and information. ICT-tools have been used to support complex reasoning, task-oriented activities, and collaborative knowledge building (Lipponen, Rahikainen, Lallimo, & Hakkarainen, 2003). Specific formalisms are tailored to facilitate specific aspects complex problem solving, and ICT-tools *coerce* [1] (Dillenbourg, 2002) people to follow the rules of such formalisms. To give some examples, ICT-tools used specific formalism to facilitate teams in diverse fields and topics as design activities (Buckingham Shum, MacLean, Bellotti, & Hammond, 1997), scientific reasoning (Suthers, 2001), and argumentation (Van Bruggen, 2003). Such tools have attained good results on cognitive aspects of group learning by focussing on task aspects. However, they have not explicitly addressed the problem of common ground in multidisciplinary teams.

[1] Some dictionary definitions (Webster's student Dictionary, 1996) of coercion hold that to coerce involves 'to constrain or force to do something'. We wish to stress that this paper uses to coerce in the sense of constraint, not force.

In this paper, we describe facilitating the negotiation of common ground. We report on NegotiationTool, a collaborative learning environment (CLE) with an embedded formalism to support negotiation processes. NegotiationTool coerces the users into exploring each other's perspectives to augment the negotiation of common ground. The optimal level of coercion is a trade-off between the impact aimed for (high coercion) and keeping the collaboration 'natural' to the users (low coercion) (Dillenbourg, 2002). Research has shown that a low level of coercion may lead to small effectiveness of a formalism, whereas high levels of coercion may disrupt collaboration to an extent that it starts to hamper collaboration.

First we describe our framework for supporting negotiation. From this framework we will then derive the design primitives for NegotiationTool, and describe three different versions of this tool, that differ with respect to the amount of coercion applied to the participants. The first research question is whether a grounding formalism facilitates the grounding process, and the second research question regards the relation of coercion and negotiation of common ground. We tested the effects NegotiationTool on the grounding process and common ground itself.

2. A framework

In Barron's study (2003), members of successful teams engaged in each other's thinking, whereas members of low performing teams typically ignored each other's proposals. Performance depended on the negotiation of a shared problem space as a basis for the construction of complex problem solutions. Team members critically explored each other's thinking, and explicitly accepted, agreed, and subsequently documented contributions to the discussion, which ultimately resulted in better problem solutions. Barron produced very useful results for the study of problem solving teams. However, her research context, sixth-grade triads solving complex problems, may impose some constraints on generalising her results.

In our framework, we address both knowledge construction to reflect on how individual knowledge becomes part of a solution to a complex problem, and group processes to reflect on the team processes that take knowledge from being in the 'mind' of one learner to becoming a team's constructed knowledge. The framework is inspired by sources on social learning (e.g., Salomon & Perkins, 1998; Sullivan Palincsar, 1998), knowledge sharing (e.g., Boland & Tenkasi, 1995; Walsh, 1995), and grounding (e.g., Baker, Hansen, Joiner, & Traum, 1999; Bromme, 2000; Clark & Brennan, 1991). It is an attempt to link the solution requirements in terms of constructed knowledge, and the group processes that underlie the construction of this knowledge.

The route from unshared knowledge in one participant's head to newly constructed knowledge in a team goes through three intermediate forms (i.e., external knowledge, shared knowledge, and common ground) via four processes, namely externalisation, internalisation, negotiation and integration (see Fig. 1).

Private knowledge is externalised when team members make their, as yet, unshared knowledge explicit or tangible to others (Leontjev, 1981), for example by making a contribution to a conversation. Once a team member has made such a contribution,

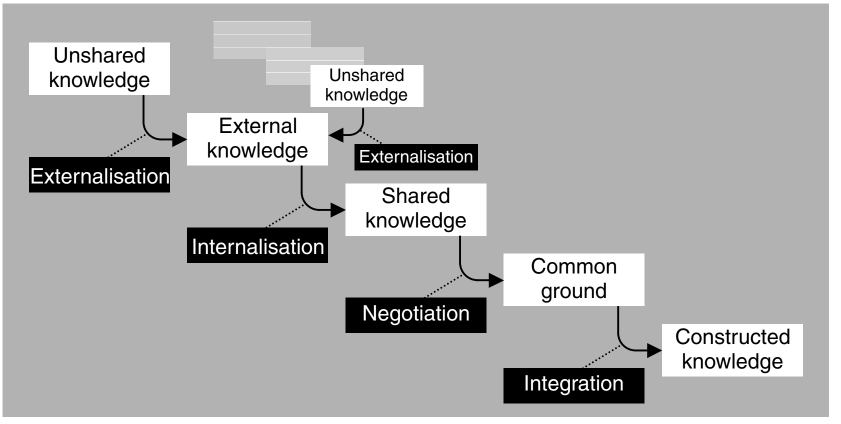

Fig. 1. From unshared knowledge to constructed knowledge.

the others can try to internalise it. While constructing their individual understanding, they can consider aspects of the contributor such as background, current situation, and views to better "understand" the contribution. Also, their own beliefs and assumptions play a role while they try to understand the contribution. A contribution is thus understood against the presumed perspective of the other, as well as against one's own perspective (Bromme, 2000). Having *shared* a contribution with a team does not mean that the team members all have arrived at the same understanding. All kinds of representational differences result from interpreting a contribution in one's own perspective only (a graphical designer has a different understanding of, and use for the term "elegance" than a computer programmer) or from minimising or rejecting its validity or plausibility due to differences in conviction or opinion.

A shared contribution is the starting point for negotiation of common ground. Common ground is a shared cognitive frame of reference (Bromme, 2000). It is through the process of internalising others' contributions, and subsequently providing feedback based on one's own perspective by word or action, that common ground can be negotiated (Alpay, Giboin, & Dieng, 1998; Baker et al., 1999). Common ground is never absolute or complete, but is continually accumulated and updated (Clark & Brennan, 1991).

We conceive of negotiation of common ground as a dual concept. *Negotiation of meaning* leads to an agreement regarding meaning and understanding of a contribution. It concerns people making public to others their private understanding of some contribution, verifying whether and to what extent their own understanding is different from what others intended them to understand, receiving feedback on this, that is clarification, re-verifying, and so on, until "the contributor and the partners mutually believe that the partners have understood what the contributor meant to a criterion sufficient for the current purpose" (Clark & Schaefer, 1989, p. 262, the grounding criterion). *Negotiation of position,* the second part of negotiation, concerns people making public to others their private opinion about a contribution, to check whether one's position is clear to others, and vice versa. One might debate, philosophically, whether opinions and truisms can be discerned from each other. Instead of getting into this debate, we want to point out that the difference between truth and opinion is assumed to be meaningful to the negotiators. Note that neither of these definitions imply the more common, generic use of the term negotiation, namely to discuss with an opposing or adversarial party until consensus or compromise is reached.

Starting from common ground, new knowledge can be built by adding new relations and concepts to common ground, via integration. Knowledge construction is based on the common ground the team has built, and will broaden and deepen the common ground because the common constructed knowledge becomes part of the common ground. With regard to problem solving, constructed knowledge represents the solution(s).

3. A formalism to support negotiation

In this section we use the above framework to construct a formalism for the support of negotiation. The steps from unshared to constructed knowledge serve as a basis for the formalism. It consists of *primitives* of negotiation, and *rules* that prescribe the use of these primitives. Primitives can be seen as basic building blocks that model a specific type of dialogue (Dillenbourg, 2002). We couple these primitives with a set of rules, to mimic the negotiation process as explicitly as possible, which results in a formalism for negotiation. Note that this formalism models an ideal negotiation process; in regular communication, the status of people's statements in terms of negotiation primitives remains implicit. The formalism must enable distinguishing between original contributions, clarifications, verifications, et cetera, making the steps explicit. By doing so, individual differences in understanding and opinion should more easily surface.

First, negotiation starts with a *contribution* (Primitive 1) of some sort, such as a hypothesis or a position, which is assumed not to be part of a team's common ground (Rule 1). To assist in detecting differences between individual representations, every team member must *verify* (Primitive 2) their understanding of another's contribution (Rule 2) because people articulate and understand the contribution against their own background knowledge (Fischer, Nakakoji, & Ostwald, 1995). Third, a contribution needs to be *clarified* (clarification, Primitive 3), using the ideas upon which it was based. For example, the educational background or the political orientation of the contributor may shed light on the meaning of his/her contribution. Nevertheless, a clarification need not always be made by the original contributor, but may also be performed by another team member who feels knowledgeable. Rule 3 is that all verifications require a clarification. Together, Rules 2 and 3 can be iterated until common understanding of the contribution is reached. Note here that a correct clarification of a contribution one team member can be seen as a successful verification by another.

The fourth primitive is *acceptance/rejection* of a contribution, which refers to whether one can judge a contribution as true (acceptance), based on the explanation given, or judges it untrue, or unintelligible (rejection). For example, the statement 1 + 1 = 10, is true only if we understand (through Rules 1 and 2) that the contributor is using the binary system. A contribution should be accepted as part of the common ground if it is true, or after it has been modified so that it has become true. Rule 4 is that every contribution needs to be accepted or rejected by the team members. Finally, Rule 5 is that people must explicitly state their own *position* (Primitive 5) on the contribution. In the case of irresolvable disagreement about previously accepted statements, Rule 5 may result in multiple scenarios, each based on another position (i.e., agree to disagree). This also means that one may accept a certain contribution, but disagree all the same, for example when neither person can prove the other wrong. In such cases, people can agree to disagree, and alternate representations that are equally legitimate can ensue.

Table 1 summarises these rules.

3.1. Negotiation tool

The formalism for supporting negotiation was implemented in an ICT-tool called the *NegotiationTool* (NTool). NTool is based on a newsgroup reader, featuring (a)synchronous, distributed, text-based discussions. To optimise the NTool for negotiations among multiple representations the formalism was implemented to structure the negotiation process in three ways, with increasing levels of coercion (cf. Dillenbourg, 2002).

Coercion refers to the degree of freedom participants are allowed in following a formalism. Coercion and formalism together constitute a collaboration script. The higher the coerciveness of a script, the more participants are required to adhere to its formalism. Scripting requires "subjects on most or all occasions to make a particular type of speech act in a specific context." (Baker & Lund, 1997, p. 176). For Dillenbourg (2002) a "script is a set of instructions regarding to how the group members should interact, how they should collaborate and how they should solve the problem." (p. 64). This means that a script can be aimed at either the interaction and collaboration level, for example by offering sentence openers or prescribing communicative acts (e.g., Baker & Lund, 1997; e.g., Barros & Verdejo, 1999; Soller, 2002) and/or the problem solving process, for example in problem-based learning. In such cases, scripting results in the use of distinct phases for discussion, with distinct purposes with regard to problem solving (Barrows & Tamblyn, 1980; Dillenbourg, 2002; O'Donnell & Dansereau, 1992).

A script that uses very little coercion leaves participants many degrees of freedom whereby usage of the formalism attains a high degree of idiosyncrasy. A script with a high level of coercion constrains the number of options participants have, thus guid-

Table 1
Rules for a formalism for the facilitation of negotiation

1. Every new issue is termed a *contribution*
2. Contributions require a *verification* by the other team members
3. Each verification is responded to with *clarification* by the original contributor
4. When all verifications are clarified, and no new verifications are performed, all team members state whether they *accept* or *reject* the statement
5. All team members state their *position* about accepted statements

ing them along the lines of the formalism. In the study reported here, three different ICT-implementations of the formalism were implemented (they are dealt with in detail in Section 4). One implementation had very little coercion, and was called the 'Idiosyncratic' version. One could compare this situation with giving a person a set of lines and symbols to be used in constructing a diagram, but leaving it up to her/him to decide which symbols and lines to use for what purpose. A second used medium coercion and was aimed at the problem-solving level (here termed 'Scripted', in appreciation of Dillenbourg's (2002) use of the word). The third used scripts aimed at the interaction and collaboration level, using high coercion and was called 'Stringent'. In each version, coercion was specifically aimed at verification and clarification primitives, that is, at the extent to which people were required to verify and clarify in specific circumstances.

NTool was expected to increase negotiation of both meaning and position because it forces people to make their private understandings and opinions public, making differences in understanding and opinion visible or salient (Bromme, 2000). More specifically, we hypothesised that (1) coercion would be correlated with negotiation, that is, the higher the level of coercion, the more negotiation. We expected this correlation to hold for both verifying and clarifying. Likewise, we hypothesised that (2) the amount of negotiation of meaning per contribution would be correlated with coercion as well. Differences were also expected with regard to common ground; (3) common ground was expected to be highest in the Stringent version and lowest in the Idiosyncratic version. All three hypotheses rest on the assumption that more coercion will make participants follow more closely an ideal model of negotiation, as laid down in the formalism. Nonetheless, differences caused by the different ways in which coercion was implemented were also exploratively studied, because scripts that are too coercive can be counterproductive if they disrupt collaboration (Dillenbourg, 2002).

4. Method

4.1. Participants

Participants were students in their senior year from the Maastricht University from the departments of Cultural Sciences, Economics and Business Administration, and Psychology. Seventeen multidisciplinary groups were formed by assigning participants from different degree programmes to teams of three. These participants were assumed to have different perspectives due to educational differences and socialisation effects from their educational careers.

4.2. Task

Participants were required to solve the ''school drop-out'' case (Kirschner, Van Bruggen, & Duffy, 2003). They received the following task description: ''You have been asked by the government to advise the Minister of Education how to solve the high school drop-out problem. At the end of the session you are expected to come up with a viable solution that can be implemented as government policy."

4.3. Formalism

Each group was supplied with NTool. Three different collaboration scripts were used.

4.3.1. Idiosyncratic

This version used only the primitives. On-screen information was presented about every contribution, and whether it needed yet to be verified or decided upon (agreeing or disagreeing). Furthermore, each participant was informed when he/she had not yet verified all contributions, and when he/she had not yet decided on all contributions.

4.3.2. Scripted

This version used the same primitives as the Idiosyncratic version, but the problem solving process was now divided into two distinct phases. Phase 1 was aimed at *negotiation of meaning*. Here participants could compose contributions, verifications, and clarifications. To end the first phase, all participants had to accept or reject all contributions. Participants were specifically informed that they were to refrain from stating opinions during this phase. Phase 2 was aimed at *negotiation of opinion* and ended when all contributions had been decided upon (i.e., there were no more contributions on the agenda). Participants were no longer allowed to compose new contributions. Using prompts, participants were informed in which phase they were.

4.3.3. Stringent

This version also used the same primitives, but allowed negotiation of only one contribution at one time. Furthermore, participants were not allowed to compose reject-, agree-, and disagree-messages before the contribution had been verified. Using prompts, participants were informed as to whether they had to verify or decide on a contribution.

Six groups used the Stringent formalism (high coercion group), five had the Scripted formalism (low coercion group) and the final six groups could use the NTool Idiosyncratically (no coercion condition).

4.4. Procedure

The procedure entailed two phases and an interview.

4.4.1. Practice phase

First the participants received a 20-min tutorial on the ICT-environment that addressed the basics of NTool communications, and then proceeded to emphasise the rules of the formalism, and the way they constrained communication. To ensure that participants were proficient with the NTool a practice case (about solving the problem of road traffic safety) was used to enable them to gain experience with the NTool. Participants practiced a total of 45 min.

4.4.2. Experimental phase

After a 15-min coffee break, participants started working on the experimental (school drop-out) case. To promote the construction of an individual problem representation, as well as to allow the researchers to determine what this representation was, participants first had to carry out the task individually (pre-test, 20 min). Participants could take notes while working individually on the task. Next, they solved the problem collaboratively (90 min), and after that individually again (post-test, 20 min). All resulting individual problem representations and solutions, as well as the group problem representation and solution were recorded. In their post-test, participants were also asked to state the points on which they felt that they had differences in opinion with their team members, to account for agreeing to disagree.

4.4.3. Interviews

Three focus group interviews were held, one for each version of NTool. The main purpose of the interviews was to derive hypotheses to interpret the potential effects of the NTool, and to explore possible effects of coercion and the formalism.

4.5. Variables and analysis

Analysis involved negotiation, common ground, and participants' perceptions of coerciveness. Two operationalisations for negotiation were used, namely *quality of negotiation* and *negotiation per conversation topic*. Negotiation was measured by analysis of the collaboration. Common ground was also measured in two ways. Firstly, by comparing individual representations before and after collaboration, and secondly, by questionnaire (Mulder, 1999). Participants' perceptions of coerciveness and effects of the formalism were measured by qualitative analysis of interview data.

4.5.1. Quality of negotiation

A coding scheme for coding function and content of messages during collaboration was developed (cf., e.g., Avouris, Dimitracopoulou, & Komis, 2003; Fischer, Bruhn, Gräsel, & Mandl, 2002; cf., e.g., Mulder, Swaak, & Kessels, 2002; Thomas, Bull, & Roger, 1982). All messages were coded with regard to:

- Cognitive content – directly related to solving the problem.
- Regulative content – related to monitoring the problem solving process, regulating the collaboration process, which also entailed tool use.
- Other content – not in any other category or non-codeable.

Messages with cognitive content were specifically coded for function. The following subcategories were used to code negotiation:

- Contribution: A new topic of conversation that has not been discussed before is introduced.
- Verification: Information is directly or indirectly requested about the intended meaning of a contribution or elaboration.
- Clarification: A reaction to a verification or a perceived lack of understanding, in which the intended meaning of a contribution or elaboration is elucidated.
- Acceptance: A reaction to a contribution in which the contribution is judged intelligible and/or correct.
- Rejection: A reaction to a contribution in which the contribution is judged unintelligible and/or incorrect.
- Agreement: A reaction to a contribution in which the sender voices his/her agreement with the contribution.
- Disagreement: A reaction to a contribution in which the sender voices his/her disagreement with the contribution.

In many cases, messages did not fit any of the above subcategories, for example if people built on each other's communications, without explicitly negotiating meaning of, or position on a contribution. Such messages were coded Elaboration: A contribution is elaborated upon by adding information or summarising.

A research-assistant was trained for 10 h to use the coding scheme (he had already received 25 h of training earlier in a comparable coding scheme). The data from the practice phase were used for training purposes. Comparing one randomly selected experimental session coded by the first author and the research-assistant resulted in a substantial (Landis & Koch, 1977) inter-rater reliability (Cohen's κ) of 0.70 (SE = 0.034). All data were coded by the research-assistant.

Verification and clarification, in contrast to elaboration, were considered indicative for explicit negotiation activities. The total number of contributions discussed was used as an indicator for the range of topics discussed.

4.5.2. Negotiation per conversation topic

To measure the number of verifications and clarifications per conversation topic, episodes in the discussion that dealt with one conversation topic were first identified. The contributions identified with the coding scheme for negotiation were considered starting points for a new discussion episode. An episode generally started with a contribution and ended when one of the participants would make a new contribution, and all of the discussion in between these contributions dealt with one conversation topic. For each group, negotiation per conversation topic was then calculated by dividing the sum of all clarifications and verifications by the number of contributions.

4.5.3. Common ground

Common ground was operationalised as the extent to which the content of individual representations was present in individual representations. To characterise the content of the individual representations the discussion content itself was characterised (see Fig. 2). The discussion episodes identified earlier served as a basis for characterising the discussion content.

Each episode was first numbered and summarised. The next step involved characterising the content of all individual representations, both initial (pre-test) and subsequent to collaboration (post-test), and the group representation. The summaries were used to identify the content within individual the representations. For every individual representation the topics that were and were not represented were assessed. For example, in Fig. 2 episode number 7 is present in Jane's initial individual representation, in the group discussion, and in all post-tests. By repeating this procedure for each of the episodes in the discussion, the origin of each conversation topic, whether it was present in the group representation, and whether participants used it in their post-tests was determined. Using these data we computed, for each group, the mean number of pre-tests and post-tests that a contribution would end up in. This mean number of post-tests per contribution was used as a measure of common ground.

We also adapted some questions from Mulder's (1999) instrument for measuring understanding, which measures various cognitive and social aspects of common ground and shared understanding. Some of the questions from the original instrument were omitted because they assumed that participants would have multiple meetings instead of one. Questions referred to understanding of the problem definition ("How well did you understand the problem definition?"), shared understanding of the problem ("To what extent did you and your group members obtain the same understanding of the problem?"), social relations between the participant and his team members ("To what extent do you feel you know the other group members?"), social relations between the other team members ("To what extent do you feel the other group members know each other?"), and problem approach ("To what extent did you and your group members agree about the problem approach?"). Questions were posed in the form of 6-point Likert-scales.

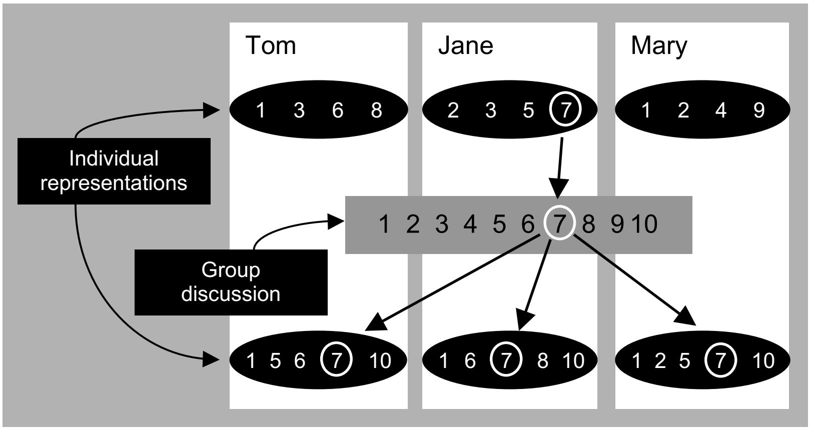

Fig. 2. Analysis of common ground; numbers indicate episodes.

4.5.4. Statistical analyses

Statistical testing was done using Kruskal–Wallis tests. Subsequent testing for the directional effects (all previously stated hypotheses) was done using Spearman's test for non-parametric correlation (i.e., verification, clarification, negotiation per contribution, and common ground). Subsequent testing for the other variables (e.g., contributions, regulations) was done for contrasts using the Mann–Whitney U test. Subsequent tests were only performed in case the Kruskal–Wallis test was significant at the 0.05-level. Testing of contrasts was also done for expected directional effects that were significantly different in the Kruskal–Wallis test, but turned out not to be correlated. All tests concerned group means ($N = 17$).

4.5.5. Interview

All participants were asked whether they wanted to join one of the interviews. Unfortunately, few participants did so, due to practical reasons of planning as well as low interest for the interviews. The Idiosyncratic focus group numbered 5 participants, the Scripted group 1, and the Stringent group 2.

The interview was conducted on the basis of a semi-structured interview guideline developed prior to the interview. The questions were directed at participants' perceptions of coerciveness in NTool. For example, participants were asked how they used NTool, what they liked and/or disliked in NTool, and how discussions in NTool differed from discussions in general. At the beginning of the interview, participants were told that all different opinions were of equal importance, and they were explicitly invited to voice dissenting views and opinions if they held such. The interviews were analysed by the first author of this paper. The interviews were videotaped and analysed using The Observer® (Noldus, Trienes, Hendriksen, Jansen, & Jansen, 2000), a software package designed for behavioural observation using video data. An open coding approach was used, which focussed on the effects of the formalism on participants' interactions, and the differences between the three versions of NTool, with special focus on coercion.

5. Results

5.1. Negotiation

We compared the different conditions with regard to number of codes (Table 2). Statistical analyses using Kruskal–Wallis tests revealed significant differences between the conditions for the number of contributions, $\chi^2(2, N = 17) = 8.85$, $p < 0.05$, number of verifications, $\chi^2(2, N = 17) = 7.08$, $p < 0.05$, number of clarifications, $\chi^2(2, N = 17) = 7.33$, $p < 0.05$, number of acceptance messages, $\chi^2(2, N = 17) = 10.58$, $p < 0.01$ and number of regulation messages, $\chi^2(2, N = 17) = 8.03$, $p < 0.05$.

Computing Spearman correlations revealed significant correlations between coercion and verification, $r_s(N = 17) = 0.63$, $p < 0.01$, and between coercion and clarifica-

Table 2
Mean numbers of negotiation primitives

	Condition		
	Idiosyncratic	Scripted	Stringent
Contribution	8.0	5.4	5.0
Verification	8.8	10.2	16.7
Clarification	10.7	9.2	17.7
Elaboration	56.6	35.6	48.5
Acceptance	3.0	13.6	1.8
Rejection	1.2	4.6	1.7
Agreement	8.7	6.0	11.7
Disagreement	1.3	1.6	2.0
Regulation	30.7	106.0	43.7
Other	8.0	8.8	5.0
n	6	5	6

tion, $r_s(N = 17) = 0.54$, $p < 0.05$. Post hoc contrasting of Idiosyncratic groups with Scripted and Stringent groups revealed a significantly higher number of contributions in the Idiosyncratic groups, $U(N = 17) = 4.00$, $p < 0.005$. Finally, contrasting of Scripted groups with Idiosyncratic and Stringent groups revealed significantly higher numbers of acceptance $U(N = 17) < 0.001$, $p < 0.005$ and regulation messages $U(N = 17) = 4.00$, $p < 0.01$ in the Scripted groups. In other words the Idiosyncratic groups made significantly more contributions, verification and clarification were significantly correlated with coercion, and the Scripted groups accepted significantly more statements, and regulated more.

Kruskal–Wallis testing revealed that the amount of negotiation of meaning per contribution (see Table 3) differed significantly between the different versions of NTool, $\chi^2(2, N = 17) = 11.17$, $p < 0.005$. Coercion was found to be significantly correlated with negotiation per contribution, $r_s(N = 17) = 0.83$, $p < 0.0005$. These results indicate that contributions were most heavily negotiated in the Stringent groups and least in the Idiosyncratic groups.

5.2. Common ground

No statistically significant differences were found with regard to pre-tests, $\chi^2(2, N = 17) = 1.78$, $p = 0.41$. The distribution of contributions across post-tests was significantly different between conditions, $\chi^2(2, N = 17) = 6.14$, $p < 0.05$. Subsequent

Table 3
Negotiation of meaning[a] per contribution

	Condition		
	Idiosyncratic	Scripted	Stringent
M	2.37	3.51	7.50
n	6	5	6

[a] The sum of all verifications and clarifications.

Table 4
Common ground

Mean number of...	Condition		
	Idiosyncratic ($n = 6$)	Scripted ($n = 5$)	Stringent ($n = 6$)
... pre-tests per episode	1.13	1.21	1.10
... post-tests per episode	1.97	2.00	2.39

Spearman correlation testing showed that the distribution of contributions across post-tests was significantly correlated with coercion, $r_s(N = 17) = 0.57$, $p < 0.05$. This means that the higher the coercion, the higher the number of post-tests a contribution would end up in (see Table 4).

Table 5 shows the self-report data for common ground. Kruskal–Wallis tests revealed significant differences for the extent to which the group held the same problem understanding, $\chi^2(2,\ N = 17) = 6.36$, $p < 0.05$ and the group understanding of the task approach, $\chi^2(2,\ N = 17) = 7.88$, $p < 0.05$. However, contrary to expectations, no correlations were found in the questionnaire data between coercion and common ground. Subsequent testing of the contrasts using Mann–Whitney tests showed that the Scripted version of NTool resulted in the lowest perception of common ground. Both the extent to which the group held the same problem understanding and the group understanding of the task approach were lowest in the Scripted groups, $U(N = 17) = 6.50$, $p < 0.01$, and $U(N = 17) = 6.00$, $p < 0.01$, respectively. Furthermore, group understanding of the task approach was highest in the Stringent groups, $U(N = 17) = 12.00$, $p < 0.05$.

5.3. *Participants' perceptions of the formalism and coercion*

Interview excerpts were coded for condition (Id = Idiosyncratic, Sc = Scripted, St = Stringent) and for interviewee (interviewees are numbered).

5.3.1. *Effects of the formalism*

The formalism may have caused the participants to refrain from immediately giving their opinions. Some interviewees noted that they were tempted to immediately give their opinion about new contributions:

> Id1 "When I saw a contribution, I first checked whether I had an opinion about it. And if so, then you're generally tempted to Agree or Disagree."

In this regard, one interviewee's observations about the various uses of verifications were relevant as well:

> Sc1: "One use [of verifications] was a normative judgement about contributions, ... [a second use was to indicate] "I just don't think it's correct," and [3] just really asking for pure clarification."

This may have influenced whether contributions were accepted, because using verifications could change participants' opinions:

Table 5
Questionnaire data

To what extent...	Conditions		
	Idiosyncratic ($n = 6$)	Scripted ($n = 5$)	Stringent ($n = 6$)
... did you understand the problem definition?	4.89	4.73	5.39
... did you and your group members obtain the same understanding of the problem?	4.72	3.80	4.67
... do you feel you know the other group members?	3.39	2.80	3.11
... do you feel the other group members know each other?	3.44	2.67	3.06
... did you and your group members agree about the problem approach?	4.50	3.87	4.89

Judgements were made on 6-point scales (the higher the number the larger the extent).

> Id1: "Through verificationing [sic] you get that people may come with knowledge you know nothing about.... while at first you may think: 'disagree', because then you don't know yet. With a clarification someone can explain something you didn't know, a theory, or a field."

However, others had less trouble not immediately giving their opinions:

> Id5: "In our group people did not have the need to immediately state their opinions. We'd first discuss some, ... and only after that people would share their opinions."

Furthermore, allowing participants to immediately agree or disagree, as in the Idiosyncratic version of NTool, did not mean that they would indeed do that:

> Id4 "If you agree, then it's not a problem. But if you disagree; ... you can't do that right away"
> Id3: "You don't disagree right away, because it's rude. You also want to explain why, and give the contributor an opportunity to react."

This remark shows that participants posted verifications instead of disagreements, even when they did in fact disagree.

From the preceding, it appears that the formalism may have affected the acceptance of some contributions. It may have caused participants to refrain from immediately giving their opinion, which afforded changing one's opinion through verification.

5.3.2. About coercion

Some interviewees using the Stringent version made some observations about coercion:

> St2: "If someone posts a verification, then the contributor should be the one to post the clarification, so you have to wait, because he can't answer two verifications at the same time."

Interviewees mentioned that they needed to be able to signal when they came up with a new point during the middle of discussing another point:

> St2: "You don't know if the others have noticed that you posted a new contribution.... In a regular discussion [in contrast to discussions in NTool] you can say that [you want to raise a new point], and then the other can still propose to return to your point later, but at least you've been able to make known that you have a point." St1: "Especially because you'll have lost your point again when the discussion's concluded."

From these statements we gather that the Stringent version may have caused some disruption because it limited discussions to one contribution only, whereas participants needed to raise other contributions at that time, or had to wait until their team mates had finished their verifications and clarifications.

Other interviewees reported that no coercion at all, as in the Idiosyncratic version, resulted in a lack of closure of discussion topics. Various interviewees remarked that they needed summaries to keep track of the discussion. Some complained about a lack of closure, a lack of being "on the same wavelength":

> Id4: "Some topics were concluded, others weren't..... I think towards the end you need the participants to be obliged to agree or disagree."

One interviewee remarked the following about the phases in the Scripted version of NTool:

> Sc1: "We felt that accept and reject were a bit redundant."

Furthermore, some interviewees noted that the formalism NTool could be improved by adding more facilities for having argumentative discussions:

> Id3: "There isn't really a place where you can convince the others that your idea is the better."

This need was also apparent from the fact that verifications were sometimes used for normative purposes:

> Sc1: "The verifications shifted from being factual to being normative. When we'd hold different opinions we'd accept that, so agree and disagree was more of a formal closure of the discussion."

The interview data suggest that to some extent argumentative discussions were taking place using verifications and clarifications. Participants may have been able to predict beforehand who would agree and who would disagree. From these statements it can be concluded that the current distinction between meaning making and position taking in the Scripted version may have had little use, especially when negotiation of position had effectively taken place in verification and clarification messages. Nonetheless, the same interviewee noted some unique uses for the reject and accept messages:

> Sc1: "You accept something because you feel that it's right.... you can disagree with it.... We used reject for contributions that we did not have enough time for, for some contributions that belonged in the chat, and one that was utter nonsense."

It can be concluded that every versions of NTool has its specific advantages and drawbacks. The interview data do not favour one version above all others.

6. Conclusions and discussion

The present research studied the relationship between negotiation, the negotiation formalism, and coercion, with the ultimate goal being to design an ICT environment that facilitates knowledge construction. The main approach was the design of a formalism for the facilitation of common ground, which appears to be a prerequisite for knowledge construction. Three versions of NTool, an ICT-tool for group discussion with a formalism for support of negotiation, were studied. The Idiosyncratic, Scripted and Stringent versions of NTool differed with regard to the extent to which they coerced participants to hold to the formalism. Coercion was expected to be positively correlated with negotiation, negotiation per contribution, and common ground.

The results showed that the three versions of NTool differed with regard to negotiation, negotiation of meaning per contribution, and common ground. Subsequent testing revealed that coercion, as we hypothesised, was significantly correlated with negotiation and negotiation per contribution. It appears that NTool does affect the negotiation of common ground, and that it does so increasingly with more coercion. With regard to common ground, the analysis of individual post-discussion representations suggests a significant correlation between coercion and common ground, as hypothesised. However, the questionnaire data about common ground revealed that the Scripted version of NTool resulted in less common ground than the other versions, as perceived by the participants.

Further analyses revealed some unexpected results. Discussions in the Scripted version of NTool featured significantly more acceptance of contributions, and regulation. Both effects may have been caused by the specific way coercion was implemented in this version. Regarding acceptance, the Scripted version used a distinct "acceptance" message-type, to be able to distinguish between the meaning-making and position-taking phases of discussion, whereas in the other versions acceptance was implicit in agreeing or disagreeing, and therefore not used in a separate message type. Regarding regulation, taking the discussion from the meaning-making phase to the position-taking phase may have caused some difficulties. For example, it may have been difficult for the participants to keep track of messages they had not verified yet, causing them to be unable to post agreement and disagreement-messages. This may have confused participants at times.

Also, analyses showed that the Idiosyncratic discussions showed significantly more contributions than the other versions. This may mean that the range of topics was widest in the Idiosyncratic version, which could suggest a trade-off between topic range and common ground. However, it may also be the case that participants in the Scripted and Stringent versions, knowing that they had less opportunity to post contributions, chose to word their contributions more broadly, in which case fewer contributions would still cover the same topic range. Further research may shed some light on these explanations.

Disruption of collaboration (Dillenbourg, 2002), which can be caused by over-scripting collaboration, may explain some of the unexpected results. The need for more regulation in the Scripted version may have caused participants perceive the least common ground, even though the analysis of the post-tests suggested otherwise. The other two versions of NTool did not seem to have any such adverse effects. In sum, NTool seems to influence both negotiation of common ground and common ground itself, and seems to do so increasingly as coercion increases. In the case of the Scripted version, the specific way coercion was implemented may have caused some disruption of collaboration. Both the Idiosyncratic and Stringent version did not seem to influence collaboration in a disruptive way.

The interview data suggested a possible mechanism for the way the formalism affects negotiation. The formalism may have restrained participants from immediately stating their opinion, in which case they may have verified their understanding instead. Subsequent clarification may have changed other's opinions from disagreeing to agreeing. The interview data did not offer any contrary mechanism, where verification may have led someone who initially agreed to disagree. In sum, it may be the case that shedding light on contributions through verification and clarification, instead of immediately taking a position, increases the chances that contributions are accepted, and become part of common ground.

The interview data also suggested more mechanisms that may have caused some disruption. The data showed that the distinction between meaning-making and position-taking (the Scripted version) may have been redundant since argumentative discussions already took place during the meaning-making phase. Furthermore, the data suggested that the Idiosyncratic version of NTool lacked affordances for closing off discussion topics. Participants experienced the agreements and disagreements as a formal way of closing the discussion topics. This may explain the possible difference in common ground between the Idiosyncratic and Stringent versions because only the participants in the Stringent version were coerced to provide post-agreement and disagreement messages, thus effectively closing off discussion topics. Finally, participants in the Stringent version could not raise a point at the time they may have wanted to raise it (i.e., a prior contribution must be closed before a new one can be made).

These results do not show that NTool was overly disruptive. The fact that some of the above mechanisms may have caused some inconveniences does not necessarily mean that communication was disrupted. A number of the issues put forward in the interviews are inherent to ICT-tools in general. Signs that can be transmitted through body language in a face-to-face situation are not available for communication in ICT-tools (computer mediated communication). Research on ICT-tools for collaborating groups has shown that such tools generally feature low participation, diverging discussions, and mixed results regarding social and context-oriented communication (Lipponen et al., 2003). However, NTool has shown that increasing coercion can result in more negotiation per contribution, which suggests less divergence of discussions. Regarding disruption, NTool does not seem to distinguish itself negatively from the average ICT-tool.

The results are promising with regard to the facilitation of the grounding process. In her study, Barron (2003) showed that interaction is important for problem solving. In her study, engaging in each other's thinking was related to better solutions. This study has shown that ICT-tools can be used to facilitate such interactions, by using a formalism for negotiation, and coercing the user into following it. However, more research is required to test our ultimate aim of facilitating complex problem solving. The present study does argue a relation between common ground and the quality of problem solutions, but does not explicitly measure it. Furthermore, the experiment took place in a single 90 min laboratory session. It remains to be seen how effective NTool is when employed in a more authentic setting, like an educational setting or a professional project team. In future experiments, we plan to take both limitations of the current study into account, by employing NTool in an educational practical setting, and by designing specific measurements for solution quality. Overall, it can be concluded that NTool and its underlying framework affect negotiation of common ground, and that adding some coercion increases this effect, without being harmful to collaboration.

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