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COMPUTER SUPPORT FOR KNOWLEDGE CONSTRUCTION IN COLLABORATIVE LEARNING ENVIRONMENTS

Abstract. As society becomes more complex, complexity becomes part of our education. Education nowadays witnesses complex problem solving tasks and multidisciplinary teamwork. Although multidisciplinarity is a prerequisite for the knowledge construction imposed by these tasks, it is in no way a guarantee. Multidisciplinary teams need common ground to enable the knowledge construction needed for complex problem solving. A framework for knowledge construction inspired the design of computer support for knowledge construction. The basic support principle consisted of making individual perspectives explicit. This principle was embedded in a collaborative learning environment in three ways, which differed in the extent to which users were coerced to adhere to the embedded support principles. High coercion, as expected, resulted in more explicit negotiation of common ground. Intermediate coercion resulted in the least common ground, because it strongly disrupted typical group processes.

1. INTRODUCTION

Present day society witnesses trends like globalisation of economies, increasing multi-culturality, and decreasing half-life of knowledge and information (Rotmans, Kemp, & Van Asselt, 2001). We find ourselves confronted with very complex or wicked problems which require multi-disciplinary and multi-stakeholder approaches in decision-making (Van Asselt, 2000). In accordance with these societal trends, higher education has increased its focus on open-ended problem solving tasks via heterogeneous, distributed teams using Computer-Supported Collaborative Learning (CSCL-) technology in which the individual team members contribute different perspectives to the task (Häkkinen, Järvelä, & Byman, 2001). Although these multiple perspectives are expected to allow for rich problem analyses and solutions (see Lomi, Larsen, & Ginsberg, 1997), it also exacts a price. Multiple perspectives may give rise to misunderstandings and disagreement among team members, threatening the problem-solving process. Achieving and maintaining common ground can therefore be seen as essential to heterogeneous teams.

This grounding problem is markedly present in distributed teams where people have to work together without meeting face-to-face. Such teams generally use CSCL- technology to share knowledge and information with each other and to build external knowledge representations, such as cognitive maps, papers, or causal diagrams.

In theory, a team may idiosyncratically use CSCL-environments where users can engage in exchanging knowledge and information in any way they wish, only limited by technological constraints. In practice, CSCL-environments often introduce additional constraints to structure conversation and discourse among collaborators. Specific CSCL-environments have been designed to facilitate teams in diverse fields and topics as design (Buckingham Shum, MacLean, Bellotti, &

Hammond, 1997), scientific reasoning (Suthers, 2001), and social awareness (Kreijns & Kirschner, 2001).

In this paper, we describe facilitating grounding in CSCL. Our main question is whether a formalism to facilitate grounding changes the grounding process, and what changes it provokes. We report on NegotiationTool, a CSCL-tool with an embedded formalism to support grounding processes. First we describe our framework for supporting negotiation. From this framework we derive the design primitives for NegotiationTool, and describe three different versions of this tool, that differ with respect to the amount of coercion that is applied to the participants. We then report on a study in which we tested the effects of the three NegotiationTool versions on the grounding process and common ground itself.

2. A FRAMEWORK

In our framework, we step-by-step describe the team processes that take knowledge from one learner to becoming a team's constructed knowledge. As mentioned above, common ground, a cognitive frame of reference between interacting people (Bromme, 2000), is essential for sharing knowledge among learners.

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 Figure 1).

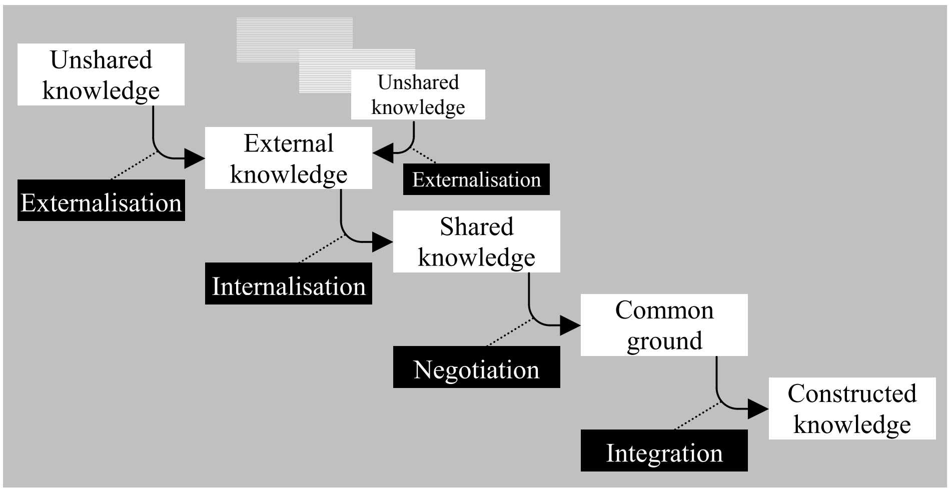

Figure 1. From unshared knowledge to constructed knowledge

Private knowledge is *externalised* when a team member makes his/her own, as yet unshared knowledge explicit or tangible to others (Leontjev, 1981). This can be oral, written, symbolic, et cetera. Once a team member has made such a *contribution*, the others can all try to *internalise* it. 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 first externalised, and subsequently internalised each other's knowledge 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 or from minimising or rejecting its validity or plausibility due to differences in conviction or opinion. Negotiation has to take place in order for the team to accept and agree upon the contribution (e.g. Alpay, Giboin, & Dieng, 1998; Bromme, 2000; Dillenbourg, Baker, Blaye, & O'Malley, 1996).

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. It is thus an iterative process that takes place 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. 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 et al., 1998; Baker, Hansen, Joiner, & Traum, 1999). Common ground is never absolute or complete, but is an interactive and ongoing process in which assumed mutual beliefs and mutual knowledge are accumulated and updated (Clark & Brennan, 1991).

Starting from the common ground, new knowledge can be built by adding new relations and concepts to the 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.

3. PRIMITIVES OF NEGOTIATION

Primitives are types of communication acts that derive from a specific dialogue model (Dillenbourg, 2002). Primitives of negotiation can thus be seen as deriving from a dialogue model of negotiation, in which each primitive serves as a basic building block of negotiation. We use the framework in the previous section to identify some "basic building blocks" or "primitives" of negotiation.

Negotiation starts with a *contribution*, e.g. a hypothesis or a position. By definition, a contribution is based upon ideas and background of the contributor. Contributions can therefore be underpinned by some sort of *clarification* by the contributor, which sheds light on the meaning of the contribution, or the opinion of the contributor. This clarification can remain implicit, for example, when the known background of the contributor sheds light on his/her contribution, but can also be made explicit. Third, *verification* is needed for contributions so as to check one's understanding of another's contribution because people articulate and understand the contribution against their own background knowledge (G. Fischer, Nakakoji, & Ostwald, 1995). The contributor thus gives a clarification, whereas the one trying to understand the contribution performs the verification.

A fourth element 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). Finally, the fifth and last primitive requires every negotiator to decide upon a *position* regarding the contribution. Consequently, one may accept a certain contribution, but still disagree, for example when neither person can prove the other wrong. In such cases, people can agree to disagree, and alternate but equally legitimate representations can ensue.

Having defined the primitives, a set of rules for negotiation is specified as follows: Every new issue added to a conversation is a *contribution* (Rule 1), and is assumed not to be part of a team's common ground. To assist in detecting differences between individual representations, every team member must *verify* whether their understanding of the contribution sufficiently matches the contributor's intent after which the contributor has to explicitly *clarify*. Rule 2 is that all contributions have to be followed by verifications by all other team members, and Rule 3 is that all verifications require a clarification. Rules 2 and 3 can be iterated until common understanding of the contribution is reached.

Rule 4 is about *accepting* or *rejecting* a statement based on one's own judgement of correctness. The statement 1 + 1 = 10, for example, 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 5 adds value judgement to the contribution. People must explicitly state their *position* on the contribution, to allow clarification/determination of perspective. This in turn aids in verification and clarification of further contributions. In the case of irresolvable disagreement about previously accepted statements, Rule 5 may result in multiple scenarios, each based on another value judgement (i.e., agree to disagree). Table 1 summarises these rules.

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 a *clarification*.
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

This formalism is expected to increase negotiation of both meaning and position because it forces people to make their private understandings and opinions public, and thus making differences in understanding and opinion visible or salient (Bromme, 2000). This will be reflected in negotiation by the number of verifications and clarifications for every contribution. By strengthening the negotiation process, we expect this formalism to increase the amount of common ground.

4.THREE ICT-IMPLEMENTATIONS OF THE FORMALISM

The formalism for supporting negotiation was implemented in an ICT-tool for (a)synchronous, distributed discussions called the *NegotiationTool* (NTool). To optimise the NTool for negotiation, the formalism was implemented in three different ways, differing with respect to the extent to which participants were *coerced* (cf. Dillenbourg, 2002) to adhere to the formalism. This section first describes scripting and coercion, and then the three versions of the NTool.

Coercion refers to the degree of freedom participants are allowed in following a script. The higher the coerciveness of a script, the more participants are required to adhere to the formalism. Dillenbourg (2002) describes a script as 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). A script can thus be aimed at either the interaction and collaboration level, for example by offering sentence openers or prescribing communicative acts (e.g., Baker & Lund, 1997; Barros & Verdejo, 1999; Soller, 2002) and/or the problem solving process, for example in problem-based learning. In the latter cases, scripting results in the use of distinct phases for discussion, with distinct purposes (Barrows & Tamblyn, 1980; Dillenbourg, 2002; O'Donnell & Dansereau, 1992). Formalisms are never script-free. A script that uses very little coercion leaves participants many degrees of freedom whereby usage of the formalism attains a high degree of idiosyncrasy.

In this study the formalism was implemented in three ways:

Idiosyncratic (very little coercion): This version used only prompting. On-screen information was presented about every contribution, and whether it needed yet to be verified or decided upon. 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.

Scripted (low coercion): This version used the same prompts as the Idiosyncratic version, but the problem solving process was now divided into two phases. Phase 1 was aimed at *negotiation of meaning*. Here participants could only compose contributions, verifications, and clarifications, and acceptances and rejections to finish 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.

Stringent (high coercion): This version used the same prompts as the Idiosyncratic, but allowed negotiation of only one contribution to be a time. Furthermore, participants were not allowed to compose reject-, agree-, and disagree-messages before the contributor had verified the contribution. Using prompts, participants were informed as to whether they had to verify or decide on a contribution.

Because of the high degree of coerciveness, the Stringent and Scripted versions were expected to result in more negotiation and common ground than the Idiosyncratic. Nonetheless, coerciveness was controlled for since scripts that are too coercive can be counterproductive if they disrupt collaboration (Dillenbourg, 2002).

5. RESEARCH STUDY

Seventeen multidisciplinary groups (triads) of senior college students given a problem-solving task were studied. Six groups were required via the NTool to use the Stringent formalism (high coercion group), five had the Scripted version of the formalism (low coercion group) and the final six groups could use the NTool Idiosyncratically (no coercion condition).

5.1. 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 teams were formed by dividing participants who majored in different subjects into groups of three. These participants were assumed to have different perspectives due to educational differences and socialisation effects from their educational careers.

5.2. Materials

Participants received a task description requiring them to solve the problem of school drop-outs: "You have been asked by the government to advise the Minister of Education as to how to solve the high school drop-out problem. You are expected to come up with a viable solution that can be implemented as government policy."

5.3. Procedure

The procedure entailed two phases. The first phase was aimed at practicing the use of the ICT-tool. In the second phase we administered the experimental case, and we gathered data about individual representations, group representations and the negotiation process.

In the practice phase the participants received a 20-minute 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. Furthermore, participants received a practice case (about solving the problem of road traffic safety) to enable them to gain experience with the NTool. Participants practiced for 45 minutes.

After a 15-minute coffee break, participants started working on the school drop-out case (experimental phase). Participants first had to carry out the task individually (pre-test, 20 minutes), to capture individual representations. Next, they solved the problem collaboratively (90 minutes), and after that individually again (post-test, 20 minutes). All resulting individual problem representations and solutions were recorded. After the post-test, the participants were asked to state to what extent the other team members would agree with their individual work.

5.4. Variables and Analysis

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 measured by comparing individual representations before and after collaboration, and by questionnaire (Mulder, 1999).

To measure *quality of negotiation*, a coding scheme for coding function and content of messages during collaboration was developed (cf., e.g., F. Fischer, Bruhn, Gräsel, & Mandl, 2002; Mulder, Swaak, & Kessels, 2002). All messages were coded with regard to *cognitive content* (directly related to solving the problem), *regulative content* (related to monitoring the problem solving process and regulating the collaboration process), and *other content* (not in another category or non-codable).

Messages with cognitive content were specifically coded for function, using eight subcategories: *Contribution* (a new topic of conversation not discussed earlier), *Elaboration* (adding information to, or summarising a contribution), *Verification* (a direct or indirect request for information about the intended meaning of a contribution or elaboration), *Clarification* (the intended meaning of a contribution or elaboration is elucidated in reaction to a verification or a perceived lack of understanding), *Acceptance* (a contribution is judged intelligible and/or correct), *Rejection* (a contribution is judged unintelligible and/or incorrect), *Agreement* (a contribution is agreed upon), and *Disagreement* (a contribution is disagreed upon).

A student-assistant was trained for 10 hours to use the coding scheme (he had already received earlier training in a comparable coding scheme). The practice data were used for training purposes. Comparing one randomly selected experimental session coded by the first author and the student-assistant resulted in a substantial (Landis & Koch, 1977) inter-rater reliability (Cohen's kappa) of .70 (SE = .034). The student-assistant coded all data.

Verification and clarification, in contrast to elaboration, were considered indicative for explicit negotiation activities. The total number of contributions discussed served as an indicator for the range of topics discussed. It was assumed that the wider the range of discussed topics, the better different perspectives were represented.

After quality of negotiation was analysed, we calculated the number of verifications and clarifications per conversation topic. First discussion episodes that dealt with one conversation topic were identified. A discussion episode generally started with a contribution (identified using the coding scheme), 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.

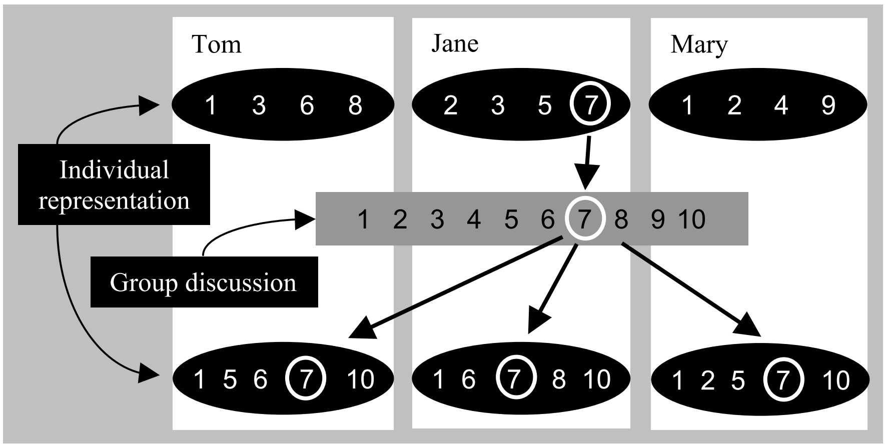

Figure 2. Analysis of common ground; numbers indicate episodes

Common ground was operationalised as the overlap in content between individual representations. The discussion episodes identified earlier were used to characterise the content of the individual representations (see Figure 2). Each episode was numbered and summarised. Then the content of all individual representations was characterised, both initial (pre-test) and subsequent to collaboration (post-test). The episode summaries were used to identify the content of the representations. For every individual representation the topics represented and those not represented were assessed. For example, in Figure 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 discussion episode, the origin of each conversation topic as well as whether participants used it in their post-tests was determined. The overlap of individual representations subsequent to collaboration was used as a measure of common ground.

We also adapted some questions from Mulder's (1999) instrument for measuring various cognitive and social aspects of common ground. 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?").

6. RESULTS

6.1. Negotiation

Statistical analyses using Kruskal-Wallis tests revealed significant differences between the conditions for the number of contributions, $\chi^2(2, N = 17) = 8.85$, $p < .05$, number of verifications, $\chi^2(2, N = 17) = 7.08$, $p < .05$, number of clarifications, $\chi^2(2, N = 17) = 7.33$, $p < .05$, number of acceptance messages, $\chi^2(2, N = 17) = 10.58$, $p < .01$ and number of regulation messages, $\chi^2(2, N = 17) = 8.03$, $p < .05$ (Table 2).

Mann-Whitney testing of contrasts was done for all significant differences found with the Kruskal-Wallis tests. Contrasting Idiosyncratic groups with Scripted and Stringent groups revealed a significantly higher number of contributions in the Idiosyncratic groups, $U(N = 17) = 4.00$, $p < .005$. Furthermore, contrasting Stringent groups with Idiosyncratic and Scripted groups revealed significantly higher numbers of verifications $U(N = 17) = 7.00$, $p < .01$, and clarifications $U(N = 17) = 6.70$, $p < .01$ in the Stringent groups. Finally, contrasting Scripted groups with Idiosyncratic and Stringent groups revealed significantly higher numbers of acceptance $U(N = 17) < .001$, $p < .005$, and regulation messages $U(N = 17) = 4.00$, $p < .01$ in the Scripted groups. In other words the idiosyncratic groups made significantly more contributions, the Stringent groups verified and clarified significantly more, and the Scripted groups accepted significantly more statements.

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

ANOVA showed that negotiation of meaning per Contribution (see Table 3) differed significantly between the different versions of NTool, $F(2, 14) = 12.39$, $p < .001$. Post hoc testing using Tukey's Honestly Significant Differences test showed that the Stringent condition differed from both the Scripted ($p < .01$) and the Idiosyncratic ($p < .001$) condition. These results indicate that contributions were more heavily negotiated in the Stringent groups than in the Idiosyncratic and Scripted groups.

Table 3. Negotiation of Meaning[a] per Contribution

	Condition		
	Idiosyncratic	Scripted	Stringent
M	2.37	3.51	7.50
SD	0.85	1.42	2.72
n	6	5	6

[a]The sum of all verifications and clarifications.

6.2. Common Ground

The difference in distribution of discussion episodes across post-tests was found to be marginally significant, $\chi^2(2, N = 94) = 4.70$, $p < .10$. No statistically significant differences were found between pre-tests $\chi^2(2, N = 83) = .973$, $p = .615$. The data in Table 4 suggest that the Stringent condition may have resulted in the most common ground, as shown by the number of discussion episodes that were present in the post-collaboration individual representations of all group members.

Table 4. Common Ground

	Condition		
Number of episodes...	Idiosyncratic	Scripted	Stringent
In one or two post-tests	29	19	13
In three post-tests	12	7	14

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, $\chi^2(2, N = 17) = 9.655$, $p < .01$ and the group understanding of the task approach, $\chi^2(2, N = 17) = 12.162$, $p < .005$. The data show that the Scripted version of NTool resulted in the lowest perception of common ground.

Table 5. Questionnaire data

	Condition		
To what extent...	Idiosyncratic	Scripted	Stringent
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 know the other group members?	3.39	2.80	3.11
do the other group members know each other?	3.44	2.67	3.06
did your group agree on the problem approach?	4.50	3.87	4.89

Note. Judgments on 6-point scales (the higher the number the larger the extent).

7. CONCLUSIONS AND DISCUSSION

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. The Stringent version, which was the most coercive, was expected to result in the most explicit negotiation, the most negotiation per conversation topic, and the most common ground.

Results showed that negotiations were more explicit in the Stringent groups than in the Idiosyncratic and Scripted groups. Furthermore, contributions were more heavily negotiated there than in the Idiosyncratic and Scripted groups. Results also showed a notable difference between the Scripted version of NTool and the other versions with respect to regulation. Apparently, taking the discussion from the negotiation of meaning-phase to the negotiation of position-phase involved much regulation. This may explain why no differences in negotiation were found between the Idiosyncratic and Scripted versions of NTool.

It is important to restate that the Scripted and the Stringent versions differed in the way they coerced the participants. Distinguishing negotiation of meaning from negotiation of position, as was done in the Scripted version, not only forces participants to negotiate, but also seems to confuse them. In the Stringent version, discussions were limited to one contribution at a time, which may have prevented such confusion. This, and coercing participants to explicitly verify every contribution (the Stringent version), resulted in the most negotiation of meaning.

The analysis of individual post-discussion representations indicated that the Stringent condition may have resulted in the most common ground. The questionnaire data about common ground showed that the Scripted version of NTool resulted in the least common ground, as perceived by the participants. It can be concluded that the Scripted version resulted in the least common ground, and that the Stringent version probably resulted in the most common ground.

In sum, we conclude that NTool and its underlying framework work, and that coercion is needed to facilitate negotiation of common ground. It is important to consider how to implement this. The Stringent version resulted in the most negotiation of common ground, because it was able to coerce participants into explicit negotiation, without confusing the discussion in the process.

AFFILIATIONS

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