Transactivity and Knowledge Co-Construction in Collaborative Problem Solving

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Abstract: Successfully engaging in collaborative problem solving is an essential constituent of professional and general life skills. Collaborative problem solving is also used to engage learners in collaborative processes relevant to the acquisition of knowledge and skills. Here, learners co-construct knowledge by transactively building on each other's contributions. In this symposium, we explore the factors leading to successful engagement in collaborative problem solving. The conceptualization of transactivity in collaborative problem solving is refined balancing the merits of both sharing new knowledge and referring to others' contributions. Empirical studies in this symposium show that it is important for successful collaborative problem solving that individuals elicit and share information with their learning partners who should evenly participate. Further, engaging in relevant collaborative processes can be facilitated by scaffolds such as sentence openers facilitating learners referring to each other.

Symposium Introduction

Collaborative problem solving is meant to engage learners in joint discourse and knowledge co-construction. CSCL research particularly inquires under which circumstances collaborative problem solving facilitates individual and joint learning (Roschelle & Teasley, 1995). Here, the most promising collaborative learning integrates both solving socio-cognitive conflicts and mutual support towards deeper understanding. Collaboratively exchanging and scrutinizing each other's ideas, arguments, and reasoning towards the problem solution is key to the co-construction of knowledge. Transactivity (i.e., learners building on each other's reasoning) has been identified as a relevant quality predicting collaborative learning outcomes. Yet, the rather general conceptualization of transactivity allows a range of different operationalizations, partly leading to inconsistent results. Further aspects in collaborative problem solving need to be considered interacting with transactive discourse and how transactivity facilitates learning. These aspects concern how activities and engagement are distributed in the group's discourse. Another aspect is how learners share information during collaborative problem solving. This highly depends on knowledge and information accessible to the learners such as prior knowledge or other resources. The emergence of these aspects in collaborative problem solving and their relevance for knowledge co-construction is being investigated in the papers collected in this symposium.

In the first paper, Vogel & Weinberger conceptualize transactivity as relevant mechanism for successful collaborative problem solving. It extends the commonly used definition by balancing the relevance of both adding novel information and building on other's contribution in collaborative discourse. The empirical studies in this symposium shed light on the above-mentioned aspects of successful collaborative problem solving and how they may be related to transactivity. The study by Hong et al. explores collaboration patterns in problem-based learning, revealing that the individual contributions in collaborative discourse are distributed less equally the more active the groups are. With more activity being related to better learning outcomes, this raises the question how equal engagement can be supported in problem-based learning. To this effect, Oshima et al. analyzed transactive discourse in collaborative problem solving using temporal network analysis. They found that the distribution of contributions in transactive discourse may not be predicted by introducing fixed or alternating leadership roles but rather by the access to and use of artifacts relevant to the problem to be solved. The paper by Brandl, Richters, et al. sheds more light on the relevance of contributing knowledge and information in collaborative problem solving. In their study about interdisciplinary problem solving in the context of collaborative diagnostic reasoning, successful learning processes were indicated by the learners' conceptual knowledge enabling them to share an adequate initial problem representation. Finally, the study by Rejon et al. compared experimentally different types of sentence starters for novelty and reference to support transactive discourse in collaborative problem solving. The analyses show that sentence starters inducing reference were linked with more engagement in socio-discursive activities expected to facilitate the co-construction of knowledge in the collaborative learning process.

Paper 1: Transactivity in collaborative learning processes: The complementary roles of novelty and reference

Freydis Vogel & Armin Weinberger

Transactivity and its effects on collaborative learning

Collaborative learners engage in reasoning within a domain, constructing knowledge through mechanisms such as productively solving socio-cognitive conflicts (Mugny & Doise, 1978). Transactivity is considered an important quality of such collaborative processes conducive to learning. Early approaches conceptualized transactivity as the mutual interdependence of verbal contributions in collaborative learning processes and their effectiveness on individual learning (Berkowitz & Gibbs, 1983; Teasley, 1997). In more recent approaches, transactivity is often broadly defined as learners building on each other's contributions with transacts in social learning ranked for their level of transactivity, including activities such as exchanging conflicting arguments or mutually developing each other's arguments (Weinberger & Fischer, 2006).

Most empirical research builds on this broad definition of transactivity and for the operationalization of transactivity, a multitude of specific learning activities are utilized (Noroozi et al., 2013) featuring different levels of reference to other's contributions. Learners from young ages show transactivity in collaborative learning autonomously, yet to various degrees (Hewitt, 2008). Although, learners have the ability to engage in transactive exchange, they are not always activated to do so. Such observations led to research on how transactivity can be facilitated in collaborative learning, for instance, by scaffolding learners with salient prompts. For the question to what extent supporting transactivity may be beneficial for various learning outcomes, empirical studies reveal heterogeneous effects of transactivity (Vogel et al., 2017). Yet, these studies use a multitude of operationalizations for transactivity and hardly distinguish between the effect of transactivity itself and the effect of other features of the focussed transacts (e.g., the cognitive elaboration induced by criticizing arguments).

Implications for the conceptualization of transactivity

The above outlined perspectives on transactivity uncover implications that demand reconsidering the conceptualization of transactivity. One issue emerges from the contradiction between the very broad definition of transactivity and its operationalization using specific activities (Berkowitz & Gibbs, 1983) mixing various features that make it impossible to distinguish between transactivity and other mechanisms of collaborative learning. While cognitive elaboration may be a beneficial mechanism of specific learning activities assumed to be transactive, it may not be a categorical feature of transactivity itself. In addition, building on each other's contributions (Teasley, 1997) may not be the only factor relevant for learning. In an extreme case it could just mean that learners take turns paraphrasing the same contributions while not making any progress in constructing new knowledge. Given the high volatility of emerging transactivity in social learning scenarios, it is also questionable how much transactivity is needed at different time points within the learning process. Heterogeneous effects shown in studies facilitating transactivity may be a hint that building on each other's contributions is differently effective for learning at different time points in a collaborative learning discourse, particularly when induced transactivity may interfere with other naturally emerging collaborative activities (Vogel et al. 2017).

Novelty and reference as defining factors for transactivity

To conceptualize transactivity as a mechanism of beneficial social learning processes, we suggest extending the traditional focus of transactivity, namely building on each other's contributions (Teasley, 1997). Given that collaborative learning and knowledge co-construction needs knowledge and information being externalized (see Brandl, et al., in this symposium), we suggest transactivity to be defined by the alternation of novelty and reference during collaboration. Through reference, contributions of learners remain mutually interconnected. Novelty enables the contributions to be enriched by new ideas and hence lays the cornerstone for collaboratively constructing new knowledge to be learned. We suggest that both novelty and reference can occur together in one contribution in a collaborative learning process. Yet, it would be plausible that more referential contributions contain less novelty and vice versa. For transactivity to be most beneficial within a contribution, it is likely that the ideal ratio of novelty and reference changes sequentially throughout the course of a collaborative learning process. For instance, in the beginning phase, novelty may naturally be more prevalent. In a phase of discussing arguments, there may be a balanced ratio of novelty and reference. Whereas in a phase of balancing arguments and building consensus, the reference factor may outweigh novelty (Weinberger & Fischer, 2006).

The design of measurements and scaffolding of transactivity in future research may operationalize transactivity more generally using novelty and reference as defining factors (see Rejon et al., in this symposium). This way, independent effects of transactivity could be distinguished from more specific effects of the activities learners carry out during collaboration (Vogel et al. 2017). Furthermore, the sequential nature of the two mutual factors of transactivity, namely novelty and reference, needs to be considered. For transactivity scaffolding this could mean that novelty and reference may be supported differently throughout the collaborative learning process. In addition, it elaborates the concept of transactivity as a generally supportive feature, towards a more sophisticated conceptualization, appreciating the varying impact of both novelty and reference within specified phases of a collaborative learning process.

Paper 2: Connecting Collaboration Patterns to Knowledge Co-construction

Daeun Hong, Suraj Uttamchnandani, Tianshu Wang, Krista Glazewski, Cindy E. Hmelo-Silver, Bradford Mott, & James Lester

In problem-based learning (PBL) within a computer-supported collaborative learning (CSCL) context, students in small groups solve ill-structured problems (Hmelo-Silver, 2003). By collaboratively engaging with the shared problems in such settings, students co-construct their knowledge of the content. For successful collective knowledge building, scaffolding is critical in these learning contexts (Saleh et al., 2020). Ideally, scaffolding supports all learners by encouraging active and equal participation, as well as collaborative learning gains. Nevertheless, scaffolding does not necessarily lead to such ideal results (Kim et al., 2018), as it must still allow for diverse ways of participating in PBL, which requires multiple pathways to solutions. The current study examined multiple small groups' engagement within a game-based PBL environment that included fixed scaffolding. We conjectured that fixed scaffolding should reduce variability in groups' knowledge co-construction and promote more even learning gains across and within groups. Thus, in this study we explored how groups engaged in collaborative learning activities within a game-based PBL environment, and how their collaborative engagement might relate to their collective knowledge gain and transactivity, which can inform how knowledge and reasoning are co-constructed over time.

Context and methods

The study was conducted in a collaborative scientific inquiry-based game called EcoJourneys, which is designed for middle schoolers to support disciplinary learning in life science and collaborative science inquiry. Seventy-one seventh grade students from three different classes participated in the study. Three to four students within a group collaboratively investigated shared problems and engaged in in-game learning activities. Using the group unit of analysis, there were 18 groups with complete data in the study. EcoJourneys consists of a tutorial followed by three quests. In each quest, students first conduct individual investigations related to aquatic ecosystems as they explore the game world. Then, they join together in the virtual world during TIDE (Talk, Investigate, Deduce, Explain) activities where they collaboratively deduce whether given claims were tenable or not by placing virtual notes containing relevant data, they have collected on one of the columns in the TIDE board. The TIDE board provides a representation to support students' collaborative sensemaking within the game.

Three data sources were used in this analysis: (1) individuals' trace data from the game; (2) group means and SDs of pre- to post-test gains on a content assessment, which indicate the level of the group's knowledge co-construction. The trace data from the TIDE activities that capture student actions in the game, such as their answers, note placement including removing and relocating a note, was extracted from the trace data logs. To identify the groups' engagement patterns, we computed mean values based on the number of actions during each TIDE activity at each quest per group to quantify the level of active participation. The standard deviation (SD) of the number of actions indicates the level of equal distribution of participation. Means and SDs were standardized to compare the values across the quests K-means clustering was used to partition the standardized values into k clusters in which each observation belongs to the cluster with the nearest mean.

Findings and discussion

We identified two patterns of engagement based on the level of groups' active and equal participation. Groups under the Low Activity-Equal Participation (Low-Equal) pattern show low activity but equally distributed participation, which means most students were not active during the TIDE activities. The other cluster is labeled as High Activity-Unequal Participation (High-Unequal) collaboration pattern, indicating one or two active members mainly engaged in TIDE activities. Meanwhile, no groups showed the High-Equal or Low-Unequal participation pattern. Taken as a whole, there is an upward-sloping trend, meaning the more students actively participate, the more variable their engagement is. In terms of the individual patterns, half of the groups showed the High-Unequal pattern at least once during game play. Across the three quests, most groups demonstrated different patterns. The number of groups with High-Unequal patterns decreases over time despite excluding fewer missing data in quest 2 than quest 3 (Table 1). In sum, there is a general trend for individual groups to demonstrate diverse engagement patterns.

Table 1
Collaboration Patterns and Group-level Knowledge Post-test in the Game Play

		Collaboration Pattern			Group-level knowledge	
Group	Pattern	Quest 1	Quest 2	Quest 3	Post-test score	SD
Higher Gain Groups[a]	High-Unequal	4	3	2	32.56	2.73
	Low-Equal	2	2	6		
	Missing[c]	3	4	1		
Lower Gain Groups[b]	High- Unequal	2	0	1	24.5	4.12
	Low-Equal	6	3	6		
	Missing	1	6	2		
Total without missing		14	8	15	28.52	5.74

[a]Higher Gain Groups designates groups whose learning gains in the post-test range from 3.00 to 11.42
[b]Lower Gain Groups designates groups whose learning gains in the post-test range from -4.67 to 3.00
[c]Missing indicates missing or incomplete data due to the technical issues

As the groups showed varied collaboration patterns with different sequences of patterns, the results also exhibited considerable variability across groups' post-test gain scores ranging from -4.67 to 11.42. Within-group variability in gain scores (SD) ranged from 0 to 14.45 across the groups. The results indicate that diverging patterns of engagement in knowledge co-construction activity is associated with less even achievement within and across groups. This suggests that we need to provide additional scaffolding by the system or teacher to facilitate all groups towards productive collaboration patterns with more even participation. As Table 1 shows, one such pattern could be the high level of active participation, particularly in the early quests. Indeed, higher gain groups show the High-Unequal pattern three times more than the other groups do throughout the gameplay and obtained much higher post-test score on average with lower variability. This leads to a conjecture that groups with the High-Unequal pattern may have more chance to engage in active knowledge co-construction by transactively building on other's contribution, while lower contributions to learning activities may happen in groups with the Low-Equal pattern. Thus, by fostering the groups' high activity, it may help enhance learning gains and promote more even learning gains within and across groups. As such, it is critical to support students' active engagement relating to knowledge co-construction activity as well which in turn should support individual knowledge acquisition. Nonetheless, this is only part of the story. Engagement patterns of some groups are inconsistent with their learning gains, and such relationships cannot be fully explained. We do not have information about what students were doing outside the game, suggesting that additional sources of information are necessary to fully understand knowledge co-construction patterns. As a result, within the PBL in CSCL environment with fixed scaffolding, there is still variability in engagement patterns of knowledge co-construction activity, which may contribute to differences in knowledge gains across the groups. To ensure more even engagement and knowledge gains, we conjecture that additional forms of scaffolding are necessary (Saleh et al., 2020).

The current study raises questions for future research. We need to better capture how students' collaborative engagement patterns shape or relate to knowledge co-construction and transactivity with trace log data. To accomplish that need additional sources of evidence to help ground truth our interpretation of patterns from the trace data and subsequently use those to provide adaptive scaffolding of student engagement.

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Paper 3: Leadership of Transactive Discourse in Collaborative Problem Solving

Jun Oshima, Ritsuko Oshima, Shotaro Yamashita, & Jun Lu

Theoretical background and research purpose

In this study, we introduce a new temporal network analysis to examine learners' transactive discourse around their ideas and each individual's contribution to their transactive discourse. The original algorithm of our temporal network analysis of discourse was to visualize a vocabulary network for identifying ideas in discourse and calculate the metrics of how each learner contributed to the final state of the vocabulary network (Oshima et al., 2012). Although it was a meaningful effort to represent the collective state of thoughts in collaborative discourse, the original algorithm could not capture the transactivity and temporal change in individual contribution to idea improvement in transactive discourse. We implemented new algorithms described in the method section (data analysis) to solve the problems. Using the new algorithm of the temporal network analysis of discourse, we examined how groups of three learners took control of the transactive discourse in collaborative problem-solving. More specifically, this study was aimed at: (1) identifying the patterns of learners' leadership of transactive discourse by the temporal network analysis and (2) examining how those patterns of leadership would happen through an in-depth interaction analysis (Jordan, & Henderson, 1995) of the video-recordings.

Method

The study's participants were 45 university students (fifteen groups of three). We asked students to collaboratively solve a Jasper Woodbury problem called "Rescue at Boones Meadow (CTGV, 1992)." In the problem, a character named Emily had to bring a wounded bald eagle back to an animal hospital using a small airplane. Participants were asked to find the fastest route from the meadow to the hospital. The problem was presented in an 18-minute video, and they were given 45 minutes to engage in collaborative problem-solving. They were also provided an iPad (to watch the video) and a whiteboard (to write/draw their ideas). Their conversations and actions were recorded on video.

The students' conversations were transcribed verbatim and subjected to two temporal network analyses. First, we modified and extended the original algorithm of the temporal network analysis to study the improvement of ideas in transactive discourse. The original algorithm examines discourse by calculating the aggregate change in the total degree-centrality (DC) of words in a vocabulary network, taking each turn in conversation as a unit of analysis. In the modified algorithm, for capturing the transactivity in discourse, we used the moving stanza-window method (Siebert-Evenstone et al., 2017). Because every conversational turn is influenced by the previous turn and influences the next turn, when participants take their transactive actions in discourse, we set a stanza-window of three conversation turns as a unit of analysis. We then calculated the cooccurrences of words in all transcribed interactions. By modifying the algorithm, we made it possible to detect which conversational turns are more transactive than others. We should carefully examine how learners engage in their transactive discourse for idea improvement.

Second, we calculated each participant's contribution to the transactive discourse by calculating the difference in the total value of the degree centralities of words based on a subset of data. Here, a target student's discourse was excluded from the original discourse data and the total discourse dataset. We then compared each participant's contribution to the transactive discourse over time.

After identifying patterns of the leadership of transactive discourse based on individual contribution, we further analyzed the discourse and participants' behaviors with artifacts they could use in more depth to understand how their leadership of transactive discourse emerged and changed over time. In particular, we were interested in the differences in the sequences of conversation turns, or discourse moves and patterns of behaviors with artifacts, between groups where all the students took their leadership in some way and those where some students failed to do so.

Results and discussion

Temporal change in transactive discourse and patterns of transactive leadership

Several patterns of the transactive discourse were identified. First, we did not find many "collective" groups where all three students engaged in transactivity ($n = 5$). Instead, many groups manifested "fixed" leadership in the transactivity, in such a way that a specific single student or specific pair engaged in transactive discourse over time, excluding the other(s) from joining in discourse ($n = 8$). In between the collective and fixed groups, we found "rotating leadership" groups where different pairs took the leadership in transactive discourse at different points of time ($n = 2$).

Differences in transactive discourse between fixed and rotating leadership groups

In the rotating leadership group, the learners' contribution to their transactive discourse, based on their ideas (i.e., solutions to the Jasper problem), were changed over time. Here, we selected one each of the fixed leadership and rotating leadership group and conducted interaction analyses (Jordan, & Henderson, 1995) to examine why and how their contributions were or were not changed throughout their whole discourse processes. First, we considered a hypothesis that conversation turn-taking would be changed over time in the rotating leadership group, compared to the fixed leadership group. In other words, students changed their leadership by taking conversation turns. To examine this hypothesis, we compared students' turn-taking proportions by dividing total conversation turns into three phases. In both groups, there was one student with significantly fewer turn-takings over the three phases, 2(2) = 40.677 in Phase 1, 58.606 in Phase 2, and 45.412 in Phase 3, all ps < .01 in the fixed leadership group and 2(2) = 12.000 in Phase 1, 14.286 in Phase 2, and 15.181 in Phase 3, all ps < .01 in the rotating leadership group. The results suggest that the proportions of turn-takings in discourse among students were stable over time and unrelated to the rotating leadership in transactive discourse.

Then, how did a student in the rotating leadership group (F2) increase their contribution to idea improvement in transactive discourse by keeping low proportions of turn-takings over three phases? Our interaction analysis of the video-recordings of the fixed and rotating leadership group revealed significant differences between them. First, participants in both groups knew each other well, and sequences of turn-takings in their discourse were stable over time. Second, their roles in their problem solving activities were constrained and empowered by artifacts around them, such as a whiteboard and iPad. In the fixed leadership group, two students, E1 and E2, largely used the artifacts. Manipulating the artifacts, E1 and E2 actively engaged in idea creation and elaboration by engaging in transactive discourse. E3 also joined the discourse by supporting their idea creation and elaboration through paraphrasing and further explanation but did not take a leading role to create and elaborate on new ideas. In the rotating leadership group, the use of the artifacts was more systematically distributed among all three participants. F1 and F3 shared a whiteboard to inscribe their ideas, and F2 watched the video on iPad for providing new information to others. The role of F2 as information provider was changed to another member for improving the idea when they thought that they did not need to watch the video.

Through our interaction analysis, we could come up with a tentative hypothesis that leadership in transactive discourse is influenced by the division of labor through collaboration. Artifacts around participants constrain their division of labor. Participants who can take control of the artifacts will lead the transactive discourse. A division of labor with artifacts is intentionally or unintentionally established. When intentionally established by participants, it may be possible for all the participants to take lead in the transactive discourse. When it is unintentionally constructed, some participants may not be able to take control of them and consequently, cannot lead transactive discourse.

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Paper 4: Predicting Success of Collaborative Diagnostic Reasoning in Agent-Based Simulations

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Successful collaborative diagnostic reasoning

Collaborative skills in domains such as medicine require expertise from multiple sub-specialties to understand underlying complex problems. One example of collaboration in professional practice is *collaborative diagnostic reasoning (CDR)*. Radkowitsch et al. (2022) proposed the CDR model to describe the CDR process based on *collaborative diagnostic activities (CDAs)* such as eliciting and sharing evidence and hypotheses. A suitable learning approach for developing complex collaborative skills such as CDR is simulation-based learning. To effectively design simulated learning environments to foster CDR, it is imperative to understand the CDR process.

The CDR process is guided by individual characteristics such as professional knowledge, collaboration knowledge, and general social skills. Professional knowledge refers to *conceptual knowledge* including declarative knowledge about constructs and *strategic knowledge* referring to the application of conceptual knowledge through problem-solving (Stark et al., 2011). Conceptual knowledge is theorized to be stored in illness scripts that are schematic mental representations of diseases with typical symptoms and findings. Illness scripts can be understood as initial problem representations directing diagnostic processes (Charlin et al., 2007). However, beyond the initial problem representation of one individual, a shared problem representation is crucial for CDR. To build a shared problem representation through co-constructing knowledge (Roschelle & Teasley, 1995), the sharing of relevant information (e.g., evidence and hypotheses) with the collaboration partner is important, yet, in practice, it is mostly done insufficiently leading to inaccurate diagnoses (Tschan et al., 2009). Therefore, beyond having *general social skills* (i.e., coordination and negotiation; Liu et al., 2015) collaboration partners need to have *collaboration knowledge* (i.e., being aware of knowledge distribution in the group; Noroozi et al., 2013). However, it has yet not been investigated in which way the CDAs and individual characteristics are related to the diagnostic outcome (i.e., accuracy of a diagnosis). We addressed the following research questions:

To what extent can CDAs and individual characteristics predict the diagnostic outcome (RQ1)? What are relevant CDAs and individual characteristics for diagnostic success in CDR (RQ2)?

Method and results

We used data from 76 medical students in a medical training simulation, whose task was to diagnose fictitious patient cases in the role of an internist while collaborating with an agent-based radiologist. Before entering the simulation, individual characteristics (i.e., conceptual, strategic, and collaboration knowledge as well as general social skills) were measured reliably in a pretest (ω = .58-.78). All interactions with the simulation were automatically stored and coded for CDAs (i.e., evidence elicitation, evidence sharing, and hypotheses sharing). The codes of CDAs were transformed into bigrams that contained information about the time spent on and transitions between the CDAs. We trained a random forest model with 10-fold cross-validation to classify whether a student, respectively, diagnostician could provide an accurate diagnosis and how important each feature is for the prediction (RQ1). Due to complex interactions among different features, the interpretation of importance is not always straightforward. Hence, to gain more insights into the relevance of the important features (RQ2), we calculated chi-square tests for the bigrams and looked at differences in individual characteristics between accurate and inaccurate diagnosticians.

Regarding RQ1 the random forest model showed a perfect prediction rate (sensitivity = 1.00, specificity = 1.00). Most important for the prediction was the transition from evidence sharing to hypotheses sharing. Other relatively important features were the time spent with hypotheses sharing, the transition from hypotheses sharing to evidence elicitation, and conceptual knowledge. With respect to RQ2, the chi-square test revealed that only the time spent with hypotheses sharing discriminated significantly between accurate and inaccurate diagnoses ($\chi^2(1) = 43.18$, $p < .001$). Spending more time with hypotheses sharing occurred more often among diagnosticians who gave an inaccurate diagnosis. Further, less conceptual knowledge is associated with inaccurate diagnoses ($U = 12511$, $p = .009$).

Discussion

Overall, based on the CDR model, we were able to predict diagnostic success from CDAs and individual characteristics in an agent-based medical simulation (Radkowitsch et al., 2022). More precisely, successful diagnosticians showed more conceptual knowledge and spent less time with hypotheses sharing than unsuccessful diagnosticians. To be successful in CDR it seems crucial to have an adequate initial problem representation which is build up from individual conceptual knowledge stored in illness scripts (Charlin et al., 2007). Well-organized illness scripts enable diagnosticians to build an adequate initial problem representation, respectively make an initial suspected diagnosis that is likely to be relevant information for the collaboration partner. This is also indicated by the less time spent with hypotheses sharing. Diagnosticians enter the collaboration with a concrete idea of the problem that enables purposeful knowledge co-construction leading to an adequate shared problem representation. Only then it is possible to engage successfully in CDAs during the collaboration.

However, in the current simulation, the collaboration partner was a standardized agent. Thus, the role of an adequate initial problem representation, respectively its crucial importance for successful CDR, needs to be investigated in human-to-human collaboration settings in which an inadequate initial problem representation could be potentially compensated by transactive processes. Besides the need of replicating our findings, an open question is the relevance of individual diagnostic activities such as the generation of evidence for an adequate initial problem representation as well as other factors potentially contributing positively to a shared mental problem representation. In conclusion, an adequate individual initial problem representation is crucial for effective knowledge co-construction leading to successful collaborative problem-solving such as CDR.

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Paper 5: Effects of Transactive Sentence Starters on Discourse Quality in Collaborative Problem Solving

Miguel Angel Rejon, Freydis Vogel, & Armin Weinberger

Transactivity in knowledge co-construction

Operating on the reasoning of others has been identified as a general mechanism underlying beneficial features of collaborative learning, known as transactivity (Berkowitz & Gibbs, 1983; Noroozi et al., 2013; Teasley, 1997). With reference to Vogel & Weinberger (in this symposium), this study focuses on two aspects of transactivity in collaborative discourse, namely novelty (i.e. contributing novel ideas) and reference (i.e. referring to other's contributions).

Transactivity in collaborative knowledge co-construction appears to various degrees in the different activities learners are engaged in. These activities can be categorized into social modes of co-construction (Weinberger & Fischer, 2006) which are expected to predict learning outcomes. Some social modes, such as externalisation of ideas relate to the transactivity aspect of novelty. Others, such as conflict-oriented consensus building, are rather related to the transactivity aspect of reference. In the present study, we explore how scaffolding transactivity can affect social modes of co-constructions in the discourse messages during collaborative problem solving. The goal of the research is to explore how scaffolding learners with transactive sentence openers for novelty, for reference, and their combination affect the number and length of messages learners exchange during collaborative discourse on different social modes of co-construction.

Method

Design and sample

In this 2×2-study students (N = 154; 117 women, 37 men; age M = 23.99; SD = 4.32) from Education and Psychology programs from universities in Germany and Austria were randomly paired and to one out of four conditions (control: n = 36, reference scaffold: n = 40, novelty scaffold: n = 40, novelty and reference scaffold: n = 38). In all conditions, learners applied attribution theory to jointly solve a problem case via a synchronous text chat for 30 minutes. Scaffolds were provided as a drop-down list containing sentence openers for either reference (e.g., "What you just wrote is…"), novelty (e.g., "A new idea about this problem case is…"), both reference and novelty, or none.

Dependent variables

Number of messages was measured as the sum of messages the dyads exchange during collaborative discourse. To identify the *social mode of co-construction,* each message was coded (Krippendorff's alpha = .74) for its predominant social mode suggested by Weinberger & Fischer (2006), namely *externalization*, *elicitation*, *quick-consensus building*, *integration-oriented consensus building*, and *conflict-oriented consensus building*. To measure the *length of messages,* for each social mode the words learners produced in all respective messages were added up, excluding the words inserted from the sentence openers.

Results

Number of messages dyads exchanged in the collaborative discourse

A 2-way ANOVA ($N = 76$ dyads) revealed non-significant effects of the novelty scaffold ($F = .76$, $p = .39$), reference scaffold ($F = .27$, $p = .60$), and their combination ($F = .33$, $p = .57$) on the number of messages shared between each dyad during the collaborative task.

A MANOVA ($N = 76$ dyads) revealed a main effect on the number of shared messages of the different social modes of co-construction for the reference scaffold, $F(5, 69) = 6.105$, $p < .001$, $\eta_p^2 = .307$ and the novelty scaffold, $F(5, 69) = 3.351$, $p < .01$, $\eta_p^2 = .195$. The interaction effect between the novelty and reference scaffolds was not significant ($F < 1$).

Post-hoc analyses indicate that dyads with reference scaffold wrote significantly less messages with *externalisations* ($M = 11.50$) and *quick consensus building* ($M = 4.18$) but significantly more messages with *integration-oriented consensus building* ($M = 6.26$) than dyads without the reference scaffold ($M = 15.71$; $M = 6.39$; $M = 4.38$). In contrast, dyads with the novelty scaffold wrote significantly less messages with *conflict-oriented consensus* building ($M = 4.03$) than dyads without the novelty scaffold ($M = 6.12$).

Length of messages dyads exchanged on different social modes of co-construction

A MANOVA (N = 76 dyads) revealed a significant main effect of the reference scaffold on the message length in different social modes of co-construction, $F(5, 69) = 6.358$, $p < .001$, $\eta_p^2 = .315$. The main effect of the novelty scaffold and the interaction effect were not significant ($F < 1$).

Post hoc analyses indicate that dyads with the reference scaffold ($M = 214.3$) used less words on their *externalisations* than dyads without the reference scaffold ($M = 292.13$). Dyads with the reference scaffold ($M = 195.37$) used more words for *conflict-oriented consensus building* than dyads without the reference scaffold ($M = 108.97$).

Discussion

The results of the study at hand points to findings about how scaffolding transactivity in collaborative problem solving can distinguish between aspects of novelty and reference. The scaffolds did not generally affect the total number of messages learners exchanged. Yet, scaffolding both novelty and reference had a distinctive impact on the number of messages and the message lengths in specific social modes of co-construction. Intriguingly, the reference scaffold increased both the number of messages on *integration-oriented consensus building* and the message length for *conflict-oriented consensus building*. As balancing different arguments towards consensus building is an important factor for knowledge co-construction and learning (Teasley, 1997), scaffolding reference seems to be needed for learners to engage in productive collaborative discourse. This is further supported by the decrease of quick consensus building and thus learners may have been more involved in cognitive elaboration (King, 2007). Yet, this was at the expense of elicitation and the missing interaction effects indicate that scaffolding novelty could not counterbalance that learners engaged less in contributing novel information. The importance of externalizing appropriate knowledge (see Brandl et al., this symposium) and the accessibility of artifacts (see Oshima et al., this symposium) raises the question how scaffolding for novelty could be improved to reach a more balanced transactive discourse. However, this study focusses on the knowledge co-construction on a social level. Further analyses need to inquire the quality of the content of knowledge contributed to the collaborative discourse and how this relates to social modes of co-construction.

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