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Facilitating learning in multidisciplinary groups with transactive CSCL scripts

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Abstract Knowledge sharing and transfer are essential for learning in groups, especially when group members have different disciplinary expertise and collaborate online. Computer-Supported Collaborative Learning (CSCL) environments have been designed to facilitate transactive knowledge sharing and transfer in collaborative problem-solving settings. This study investigates how knowledge sharing and transfer can be facilitated using CSCL scripts supporting transactive memory and discussion in a multidisciplinary problem-solving setting. We also examine the effects of these CSCL scripts on the quality of both joint and individual problem-solution plans. In a laboratory experiment, 120 university students were randomly divided into pairs based only on their disciplinary backgrounds (each pair had one partner with a background in water management and one partner with a

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background in international development studies). These dyads were then randomly assigned to one of four conditions: transactive memory script, transactive discussion script, both scripts, or no scripts (control). Learning partners were asked to analyze, discuss, and solve an authentic problem that required knowledge of both their domains, i.e., applying the concept of community-based social marketing in fostering sustainable agricultural water management. The results showed interaction effects for the transactive memory and discussion scripts on transactive knowledge sharing and transfer. Furthermore, transactive memory and discussion scripts individually, but not in combination, led to better quality demonstrated in both joint and individual problem solutions. We discuss how these results advance the research investigating the value of using scripts delivered in CSCL systems for supporting knowledge sharing and transfer.

Keywords Collaborative learning · Computer-supported collaborative learning · Multidisciplinary groups · Transactive discussion script · Transactive memory script

Learning processes and outcomes for students who are asked to collaborate with peers have been of interest to many researchers in psychology, learning sciences, and education. Given the increasingly global nature of the workplace and the need for multidisciplinary expertise to solve today's complex issues, helping students learn how to work together in groups to share their knowledge, expertise, and experiences from different disciplinary perspectives is a priority for higher education.

Multidisciplinary groups can be advantageous to learning when students leverage one another's complimentary expertise to create new ideas and products in a way that would have been difficult with single disciplinary thinking (e.g., Boix-Mansilla 2005; Mansilla 2005). Although considering a problem from various viewpoints can be productive, some studies have shown that multidisciplinary groups do not always produce good problem solutions (e.g., Barron 2003; Vennix 1996). In this study, we aim to provide solutions for challenges that are inherent to multidisciplinary collaborative problem-solving settings using a transactivity approach. Transactivity is a term derived from Berkowitz and Gibbs (1983) and introduced to collaborative learning by Teasley (1997) meaning "reasoning operating on the reasoning of the other".

There are two main reasons that multidisciplinarity may not always be an advantage. First, multidisciplinary learners need to establish common ground, which is vital to team performance but difficult and time consuming to achieve (Beers et al. 2005, 2007; Courtney 2001). Group members may engage in non-productive discussions of information that may already be known to all members (Stasser and Titus 1985). As a consequence, some groups work together for extended periods before actually starting to work efficiently on pooling their unshared knowledge. This outcome is striking since in order for productive collaborative problem solving to succeed, group members need to effectively pool and process their unshared complementary knowledge and information rather than engage in discussion of the information that is already shared among team members from the start (e.g., Kirschner et al. 2008; Rummel and Spada 2005; Rummel et al. 2009). Speeding up the process of pooling unshared information is more likely to be achieved when group members have meta-knowledge about the domain expertise and knowledge of their learning partners (e.g., Noroozi et al. 2013a; Rummel et al. 2009). This process has been described as developing a Transactive Memory System (TMS; Wegner 1987, 1995).

Second, due to divergent domains of expertise, group members may have difficulties building arguments for and against those being put forward by their learning partner(s); and therefore avoid engaging in transactive discussions. In order to make decisions leading to joint solution(s) in collaborative problem-solving settings, learning partners need to engage in transactive discussion and to critically evaluate the given information from different perspectives on the basis of their domains of expertise (Rummel and Spada 2005; Rummel et al. 2009) before they reach an agreement and consensus about solution(s). Facilitation of transactive discussions is more likely to be achieved when group members are guided to elaborate, build upon, question, construct arguments for and contra-arguments against the contributions of their learning partners in order to reach shared solution(s) for the learning task (Stegmann et al. 2007; Noroozi et al. 2013b; Teasley 1997; Weinberger et al. 2005, 2007).

In summary, there seem to be two types of collaborative discussion that support group learning: First, effective collaborative learning has been found to be related to the process by which learners gain meta-knowledge about the domain expertise of their partners and use this knowledge to pool and process unshared information, thus establishing a TMS. Second, effective collaborative learning depends on how learners engage in transactive discussion when they elaborate, build upon, question, construct arguments and give contra-arguments against the contributions of their learning partners (Noroozi et al. 2013b). Given these research findings, platforms for online learning environments such as ICT tools or CSCL systems have been designed to increase knowledge sharing and transfer as well as argumentative knowledge construction (Weinberger and Fischer 2006; Weinberger et al. 2007). Scripts have been shown to be a promising approach to orchestrate various roles and activities of learners in CSCL. CSCL scripts can be used as an approach for procedural scaffolding of specific interaction patterns implemented into online learning environments (Fischer et al. 2007; Weinberger 2011). This study aims to foster transactive knowledge sharing and domain-specific knowledge transfer in a multidisciplinary CSCL setting using transactive memory and discussion scripts. A transactive memory script is a set of "role-by-expertise" prompts for building awareness about a learning partner's expertise, assigning and accepting task responsibility, and forming a collaboratively shared system for retrieving information based on specialized expertise. A transactive discussion script is a set of "elicit-and-integrate" prompts for making analyses of the argument(s) put forward by learning partners and constructing arguments that relate to already externalized arguments. In addition, we examine the individual and combined effects of these two kinds of scripts on the quality of both joint and individual problem solutions.

Collaborative learning

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In an increasingly global economy, it is inevitable that professionals in all fields will be confronted with rapidly changing problems and complex issues. These complexities call for appropriate specialization of domain knowledge, but they also make it necessary for qualified professionals and experts from different disciplines to collaborate in new learning and working contexts. This reality has consequences for education, especially for providing students with ample experience working in multidisciplinary groups. In educational settings, collaborative learning tasks are designed to provide group members with experience working together on complex and authentic tasks (Dillenbourg 1999), and elaborating on learning materials without immediate or direct intervention by the teacher (Cohen 1994). Building on Stahl (2006), in collaborative communities, learning takes place at the level of groups and communities as well as on an individual level. Collaborative learning can be viewed with a focus on individual cognitions that can be exchanged in the form of discourse contributions between individual members in the group. Through this process, learners generally contribute individually to solving the problem, partake in discussion of all contributions, and arrive at joint solutions by working together (Roschelle and Teasley 1995). Some evidence has been collected on the role of individual cognition and discourse in collaborative learning showing that deep cognitive elaboration is a good predictor for learning outcomes, which can sometimes diverge from the quality of the arguments brought forward (Stegmann et al. 2012).

However, there is a contrasting approach that views collaborative learning as integral to group cognition. This approach focuses on the interactional understanding of referencing and meaning making outside the individual minds in collaborative communities. Based on the notion of group cognition in collaborative learning communities, knowledge building relies on the collective, distributed cognition of a group/community, as a whole unit, rather than individual mental representations (Bereiter 2002; Stahl 2006). From this perspective, collaborative knowledge building often could not be attributed to individuals or even a combination of individual contributions, but instances of group cognition as a whole. Although there has been some conceptual grounding on learning through discourse and recent work has focused on group-level phenomena of collaborative learning (e.g., Paus et al. 2012), there is yet little research on how individual contributions emerge and re-emerge in discourse and may become part of individual knowledge structures as a result of that exchange.

Despite the diversity of theories and different nuances in the socio-cognitive theories employed to understand the process of collaborative learning (Stahl 2011b), there has been a consensus among researchers that learning is the result of interaction or transaction between the partners in a group (De Lisi and Golbeck 1999; Michinov and Michinov 2009). In the following paragraphs, we describe how both transactive memory system (TMS) and transactivity are considered to be important for collaborative learning in multidisciplinary groups with divergent knowledge. Whilst TMS (Wegner 1987, 1997) refers to coordination of the distributed knowledge among members of a group, transactivity (Teasley 1997) refers to the extent to which learners operate on the reasoning of their peers during collaborative learning.

Transactive memory system (TMS) in collaborative learning

Wegner (1987) was one of the pioneers of the concept of TMS. His theory of TMS was used originally to describe how couples and families in close relationships coordinate their memories and tasks at home. A TMS is based on the interaction between individuals' internal and externally supported memory systems, in the form of communication between group members (Wegner 1987, 1995). Internal memory is defined as unshared information located in the individual mind, whilst external memory is knowledge represented outside the mind of a group member that can be shared through knowledge-relevant communication processes among group members (Wegner 1987, 1995). In TMS, group members need to look for external memories to identify the existence, location, and mechanisms for retrieval of knowledge held by other group members. TMS can be described as a system, which combines the knowledge stored in each individual's memory with meta-memory on knowledge structures of the learning partner(s) for developing a shared awareness of who knows what in the group (Moreland et al. 1996, 1998; Wegner 1987, 1995).

More specifically, TMS refers to group members' awareness of one another's knowledge, the accessibility of that knowledge, and the extent to which group members take responsibility for providing knowledge in their own area of expertise and retrieval of information held by other group members (Lewis 2003; London et al. 2005; Wegner 1995). These processes can result in the forming of a collaboratively shared system of encoding, storing, and retrieving information in the group as a whole for enhancing group performance (Wegner 1995). Following Wegner's work (1987, 1995), group members work best when they first discover and label information distributed in the group, then store that information with the appropriate individual(s) who has/have the specific expertise and, finally, retrieve the needed information from each individual when performing a task some time later (see Noroozi et al. 2013a, for a full description of various processes of a TMS). Establishment of a TMS in a group helps members start a productive discussion in order to pool and process learning partners' unshared information and knowledge resources, leading to successful completion of a collaborative learning task (Moreland and Myaskovsky 2000; Rummel et al. 2009; Stasser et al. 1995).

Information pooling and processing can be facilitated through TMS since members of a group are asked to externalize their own unshared knowledge for learning partners and then, on the basis of this externalized information, they can ask critical and clarifying questions in order to elicit information from learning partner(s) (e.g., Fischer et al. 2002; Webb 1989; Weinberger et al. 2005, 2007). Elicitation of information (e.g., asking questions to receive information from learning partners) could again lead to externalization of information (e.g., through explanations by learning partners) which may lead to a successful exchange of unshared information among members of a group in collaborative problem solving (King 1999; Weinberger and Fischer 2006; Weinberger et al. 2005, 2007). Both externalization of one's own knowledge and elicitation of a learning partner's knowledge are considered to be mechanisms that support learning due to the facilitation of information pooling among members of a group in collaborative settings (Fischer et al. 2002; King 1999; Rosenshine et al. 1996).

Transactivity in collaborative learning

Transactivity, i.e., "reasoning operating on the reasoning of the other," is a term derived from Berkowitz and Gibbs (1983) and introduced to collaborative-learning literature by Teasley (1997). Transactivity indicates to what extent learners build on, relate to, and refer to what their learning partners have said or written during the interaction. Transactivity has been regarded as one of the main engines of collaborative knowledge construction and is connected to the level of cognitive elaboration and individual knowledge construction. Specifically, the more learners build on the reasoning of their learning partners, the more they benefit from learning together (Teasley 1997). Successful collaboration typically requires that learners engage in transactive discussions and argumentation sequences before reaching an agreement with their peers on joint solution(s) (Teasley 1997; Rummel and Spada 2005; Rummel et al. 2009).

Failure of group members to build on the reasoning of their learning partners may prohibit them from engaging in critical and transactive discussions, as they too quickly accept the contributions of their peers (Weinberger and Fischer 2006). This quick consensus building represents the lowest level of transactivity as learners immediately accept the contributions of their partner(s) without further discussion. This often happens when learners want to manage the interaction and continue the discussion focused on other aspects of the learning task, rather than because they are already in agreement (Clark and Brennan 1991; Weinberger and Fischer 2006).

By contrast, when learners operate on the reasoning of their learning partners, they integrate and synthesize one another's perspectives and ideas in order to jointly make sense of the learning task (Nastasi and Clements 1992; Noroozi et al. 2013b; Weinberger and

Fischer 2006). This form of transaction has been called "integration-oriented consensus building" as learners engage in persuasive argumentation with partner(s) in order to revise, modify, and adjust their initial contributions on the basis of their partner(s)' contributions (Fischer et al. 2002; Weinberger and Fischer 2006). In another form of transactivity, called "conflict-oriented consensus building", learners closely operate on the reasoning of their partners based on their socio-cognitive conflicts about their individual positions on the solution(s). This form of consensus building happens when learners engage in a highly transactive discussion and critical argumentations with their partner(s), which can lead to disagreements and therefore modifications of the perspective of the partners (Fischer et al. 2002; Weinberger and Fischer 2006). Conflict-oriented consensus building is regarded as an important type of consensus for leading toward a successful collaborative learning experience (Doise and Mugny 1984; Fischer et al. 2002; Weinberger et al. 2005).

Computer-support systems to facilitate TMS and transactivity

In the last 15 years, virtual environments in the form of ICT tools or online support systems have been found to facilitate information pooling and knowledge awareness, and to support transactive discussions. Despite all the problems and challenges that are inherent to collaboration in online and networked learning environments such as production of descriptive and surface-level knowledge (see Häkkinen and Järvelä 2006) as well as difficulties for achievement of reciprocal understanding and shared values (see Järvelä and Häkkinen 2002), CSCL environments in which learners collaborate in teams have been found to support knowledge construction and learning. The two most prominent instructional approaches in CSCL used to facilitate transactivity are knowledge representation tools and computer-supported collaboration scripts (see Noroozi et al. 2012c, for an overview). The most popular knowledge representation tools to facilitate knowledge awareness and sharing in the group are graphical concept maps (e.g., Dehler et al. 2008, 2011; Engelmann and Hesse 2010, 2011; Noroozi et al. 2011, 2012a, b; Schreiber and Engelmann 2010). There is an assumption that group awareness is a prerequisite for initiation of TMS in collaborative settings. For example, Schreiber and Engelmann (2010) found that using concept maps to visualize collaborators' knowledge structures (see also Engelmann et al. 2009) can initiate processes of TMS development, which is in turn beneficial for group performance in newly formed ad hoc groups.

The effects of computer-supported collaboration scripts on knowledge awareness and sharing for facilitation of TMS in multidisciplinary collaborative settings are still unclear. This is striking since scripts can be textually implemented into the CSCL platform in a variety of forms such as cues, prompts, input text boxes etc. to foster both collaborative and individual learning (e.g., Fischer et al. 2002; Rummel and Spada 2005; Rummel et al. 2009; Schellens and Valcke 2006; Schellens et al. 2007, 2009; Stegmann et al. 2007; Weinberger et al. 2005). The notion of scripting was inspired by the early success of using scripted cooperation to promote collaborative learning activities within the context of natural sciences (O'Donnell 1999). Collaboration scripts provide detailed and explicit guidelines for small groups of learners to clarify what, when and by whom certain activities need to be executed (Weinberger et al. 2007). CSCL scripts have often been realized through prompts, which are mostly embedded in the graphical user-interface of the collaboration tool (Baker and Lund 1997). Prompts may sometimes take the form of sentence starters (Nussbaum et al. 2004) or question stems (Ge and Land 2004), and provide learners with guidelines, hints and suggestions that facilitate the enacting of scripts (Ge and Land 2004; Weinberger et al. 2005, 2007).

Scripts have not yet been related to the construction of TMS in spite of the fact that scripts distribute resources and roles explicitly and hence enhance learners' awareness of how knowledge is distributed within a group (Weinberger 2011). Scripts have been designed to foster transactive talk and discourse and have been found to substantially facilitate individual learning outcomes as well as knowledge convergence within a group of learners (Weinberger et al. 2005, 2007). Despite the research on the role of collaboration scripts and its promising findings on various aspects of learning mechanisms – especially the facilitation of transactive talk and discourse – in mono-disciplinary groups, only few research studies have so far reported on the effects of these scripts on learning for groups comprised of members with different disciplinary backgrounds. Studies by Beers et al. (2005, 2007), Kirschner et al. (2008), as well as Rummel and Spada (2005) and Rummel et al. (2009) focused on the role of ICT tools and online support systems for facilitation of collaborative learning in multidisciplinary settings. However, the focal points of these studies were not on the effects of CSCL scripts on TMS and transactive discussions.

Research questions

To date, research has not focused systematically on the joint operation of the TMS and transactivity in a CSCL environment with appropriate support measures. It is unclear how transactive knowledge sharing and domain-specific knowledge transfer can be facilitated in a multidisciplinary CSCL setting. The picture is even less clear when it comes to whether and how transactive memory and discussion scripts improve the quality of joint and individual problem solution plans in a multidisciplinary CSCL setting. Therefore, the following research questions were formulated to address these issues:

1. To what extent is the quality of student messages during the collaborative phase in terms of *transactive knowledge sharing* affected by a transactive memory script, a transactive discussion script, and their combination in a multidisciplinary CSCL setting?

   It was expected that the transactive memory script would facilitate coordination of the distributed knowledge, which in turn would facilitate transactive knowledge sharing in terms of externalization of each participant's own knowledge and elicitation of their learning partner's knowledge. It was also expected that the transactive discussion script would facilitate collaborative discussions and argumentations, which in turn would facilitate transactive knowledge sharing in terms of integration and conflict-oriented consensus building. Furthermore, we expected that when offered in combination the scripts would each have these same effects, but we did not expect any interaction effects.
2. To what extent is *domain-specific knowledge transfer* (individual-to-group, group-to-individual, and shared knowledge transfer) affected by a transactive memory script, a transactive discussion scrip, and their combination in a multidisciplinary CSCL setting?

   It was expected that facilitation of both coordination of the distributed knowledge and collaborative discussions and argumentations would be reflected in the domain-specific knowledge transfer. We expected no interaction effects of the two scripts when offered in combination.
3. To what extent is the *quality of joint and individual problem solution plans* affected by a transactive memory script, a transactive discussion script, and their combination in a multidisciplinary CSCL setting?

   It was expected that both scripts would improve quality of joint and individual problem solution plans. We expected no interaction effects of the two scripts when offered in combination.

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Method

Context and participants

The study took place at Wageningen University in the Netherlands, which has an academic focus on the Life Sciences, especially food and health, sustainability, and a healthy living environment. Students at this university are encouraged to combine natural and social sciences: such as plant sciences and economics, or food technology and sociology (see Noroozi et al. 2012a). The study participants were 120 students from two disciplinary backgrounds: 1) international land and water management, and 2) international development studies. These two complementary domains of expertise were required to successfully accomplish the learning task in this study. The mean age of the participants was 24.73 (SD=3.43) years; 57 % were female and 43 % were male. The group of participants was made up of an approximately an even number of Dutch and foreign students. Students were compensated €50 for their participation in this study.

The participants were assigned to partners based on disciplinary backgrounds, so that one partner had a water management disciplinary background and the other an international development disciplinary background. The participants in each pair did not know each other beforehand. Next, each pair was randomly assigned to one of four experimental conditions in a 2×2 factorial design, each of which included 15 pairs. Participants in three conditions were given scripts – either transactive memory, transactive discussion, or a combined script – and the control group was not given a script. The experimental conditions differed only with respect to the components of transactive memory and discussion scripts that were implemented in the platform using the interface of the online environment (see description below).

Learning material

Students participating in the study were asked to learn the concept of Community-Based Social Marketing (CBSM) and its application in Sustainable Agricultural Water Management (SAWM). Specifically, the participants were asked to apply the concept of CBSM in fostering sustainable behaviour among farmers in terms of the principles of SAWM. In the collaborative learning phase (see Table 1), learners were asked to analyze and discuss the problem case and to design an effective plan for fostering sustainable behaviour for SAWM as a solution. They were asked to take into account the farmers' various perspectives on the need – or lack thereof – of implementing SAWM. The learning task was authentic and complex, and allowed learners to construct different arguments based on the concepts of CBSM and SAWM.

CBSM is based on research in the social sciences demonstrating that behaviour change is most effectively achieved through initiatives delivered at the community level which focus on removing barriers to an activity while simultaneously enhancing the activity's benefits. Students with an international development studies background were expected to have knowledge on CBSM. To be included in the study, they must have passed at least two courses in which the concept of CBSM or related topics had been studied (M=3.79; SD=1.61).

SAWM can be defined as the manipulation of water within the borders of an individual farm, farming plot, or field. SAWM seeks to optimize soil-water-plant relationships to achieve a yield of desired products. SAWM may therefore begin at the farm gate and end at the disposal point of the drainage water to a public watercourse, open drain, or sink.

Table 1 Overview of the procedure of the experimental study

Phase	Duration
(1) Introduction and pre-test phase	35 min
Introductory explanations	5 min
Assessment of personal data (questionnaires)	10 min
Assessment of collaboration and computer experiences, learning style, argumentation skill etc. (questionnaires)	20 min
(2) Individual learning phase	40 min
Introductory remarks	5 min
Individual study phase of the theoretical text (conceptual space and problem case)	15 min
Pre-test of domain-specific prior knowledge (individual analysis)	20 min
(3) Collaborative learning phase	90 min
Introduction to the CSCL platform	5 min
Explanation of the procedure	5 min
Collaborative learning phase (online discussion)	80 min
(4) Post-tests and debriefing	45 min
Individual analysis of the problem case	20 min
Assessment of satisfaction with the learning effects and subject learning experience	20 min
Debriefing	5 min
Total time	about 3.5 h

Students with an international land and water management studies background were expected to have knowledge of SAWM. To be included in the study, they must have passed at least two courses in which the concept of SAWM or related topics had been studied (M=3.45; SD=1.09).

To avoid any possible knowledge overlap between students in the academic content areas (SAWM and CBSM), they were asked to write down all past courses they had taken which concerned the domain expertise of the learning partner. None of the students had taken any courses in their partner's domain. In order for the learning partners to understand each other and to be efficient in a multidisciplinary setting, all learners were provided with a three-page description of both CBSM and SAWM, and the demographic characteristics of the farmers and geographical characteristics of the location. This three-page description helped learners to share some knowledge that was useful to master the learning task. The description of the problem case and theoretical background were embedded in the platform during collaboration, so that the learners could study them when interacting with their partners.

Learning environment

The partners in each dyad were located in two separate laboratory rooms. An asynchronous text-based discussion board called SharePoint was customized for the purpose of our study for the collaboration phase. Immediate (chat-like) answers were not enabled in the learning environment. Instead, the interactions were asynchronous, resembling e-mail communication for the exchange of text messages (see Noroozi et al. 2013b). During the collaborative phase, the learners' task was to collaboratively analyze, discuss, and solve the problem case on the basis of the theoretical background and to arrive at a joint solution. The goals were for the partners to (1) to learn from each other with respect to the domain-specific theoretical concepts of their learning partners, (2) to share as much knowledge as possible during collaboration, and (3) to discuss and elaborate on the theoretical concepts in each partner's specific domain to collectively design sound (individual and joint) solution plans for the problem case. In other words, participants were expected to combine their complementary domain-specific knowledge, and then to discuss and elaborate on this information such that it could be applied for designing solution plans for the problem case.

Each message sent to a partner consisted of a subject line, date, time, and the message body. While the SharePoint platform set author, date, time, and subject line automatically, the learners had to enter the content of the message as in any typical discussion board. The platform was modified to allow for textual implementation of computer-supported collaboration scripts. The CSCL environment for learners in the experimental conditions was the same as for the control group, except for the presence of a transactive memory script, a transactive discussion script, or combined scripts, which structured the discussion phase in the platform. The conditions were distinguished and implemented as follows:

The control group

The learning partners received no further support beyond being asked to analyze, discuss, and solve the problem case on the basis of the theoretical background provided by the platform and to type their arguments into a blank text box.

Transactive memory script

The platform in this condition was the same as in the control group except for the addition of a transactive memory script. Building on Wegner (1987), we developed a script that spanned three phases: encoding, storage, and retrieval (see Noroozi et al. 2013a). For each phase, specific types of prompts were embedded in the CSCL platform; however, all replies by learning partners were not structured by a prompt. In the encoding phase, learners were given 10 min to introduce themselves, compose a portfolio of their expertise, and indicate what aspects of their expertise applied to the given case. They were prompted to present their specific expertise, not general knowledge, in the portfolio message. Therefore, the content of the initial messages was pre-structured with prompts (e.g., "Briefly sketch the knowledge areas you have mastered in your studies so far…"; "Indicate what aspects of your expertise apply to this case…"; "Indicate what other knowledge might be relevant to this case…").

In the storage phase, the dyad members were given 15 min to read the portfolios and discuss the case with the goal of distributing responsibility for various aspects of the learning task. Respective prompts aimed at helping the students to identify what expertise should be applied to what aspect of the task and to take responsibility for those aspects that matched their own expertise. The content of the initial messages in this phase were pre-structured with prompts, such as: "The following aspects of the task should be analyzed by…"; "I will take responsibility for the following aspects of the learning task…". The dyad members were asked to compose at least one task distribution and one acceptance of responsibility message.

In the retrieval phase, the dyad members were given 15 min to analyze and solve previously assigned parts of the task based on their specific expertise. Again, the content of the initial messages was pre-structured with prompts (e.g., "The task aspects related to expertise XY are addressed as follows…"; "The task aspects related to expertise YX are addressed as follows…").

The learners were then given 40 min and guided to combine their solutions on the basis of their specialized domains of expertise. They received prompts to construct a joint solution, to consider both areas of expertise in a balanced way, and to indicate agreement on the solution. The content of their initial messages was pre-structured with prompts such as "The two aspects of the task interact in the following way…"; "To adjust and combine our solutions, I suggest that…".

Transactive discussion script

The platform in this condition was the same as in the control group except for the addition of a transactive discussion script, which structured the replied messages in text windows (see Noroozi et al. 2013b). Every dyad member was first asked to individually analyze the problem case and then to submit that analysis into a blank text box. The learning partners were then asked to discuss the case on the basis of one another's individual analysis while receiving a respective prompt that applied to every reply they sent. Building on a modified coding scheme from Berkowitz and Gibbs (1983), four types of prompts were automatically embedded into the reply messages in the text windows, each of which was expected to facilitate transactive knowledge sharing. Specifically, each participant was asked to paraphrase, criticize, ask clarifying/extension questions, give counter-arguments, and propose integration of arguments in response to each message that had been posted by the learning partner until they reached consensus and indicated agreement on the solutions. Learners could either start a new topic by posting a new message or reply to messages that had been posted previously. The structure of the four prompts was as follows:

1) *The prompt for argumentation analysis and paraphrasing the elements for the construction of a single argument in accordance with a simplified version of* Toulmin's (1958) *model (claim, ground, and qualification)*. Learners were first asked to analyze the case and write their own argument(s) in the discussion board. They were then required to make analyzes of the argument(s) being put forward by their partners and paraphrase them in pre-structured boxes. Therefore, the subjects of the reply messages were pre-structured with prompts (e.g., "You claim…"; "Building on the reason…"; "The noted limitation of your claim is…"). Learners were encouraged to construct sound, explicit analyses of their partners' arguments.
2) *The prompt for feedback analysis focusing on clarification of the problem case on the basis of individual analysis of the learning partners' arguments* (see also Weinberger et al. 2005, 2010). The subjects of the reply messages were pre-structured with prompts for feedback analysis (e.g., "I (do not) understand or agree with the following aspects of your position…"; "Could you please elaborate on that…"; "… is not yet clear to me; what do you mean by that…").
3) *The prompt for extension of the argument focusing on further explanation and development*. The subjects of the reply messages were pre-structured with prompts for extension of the argument (e.g., "Here's a further thought or an elaboration offered in the spirit of your position …").
4) *The prompt for building counter-arguments and interactive arguments for different areas of expertise in accordance with* Leitão's (2000) *model of argumentation sequence (argument–counterargument–integrative argument…)* (see also Stegmann et al. 2007). The subjects of the reply messages were pre-structured with prompts for construction of argumentation sequences (e.g., "Here's a different claim and the reasoning behind it from my area of expertise…"; "To adjust and combine our solutions, I would suggest that…").

The combined script

The CSCL platform in this condition was the same as in the control group except for the addition of the combined transactive memory and discussion scripts. The subjects of the original messages were pre-structured with various prompts as in the transactive memory script. Each reply was also pre-structured with the four types of prompts as in the transactive discussion script.

Procedure

Before carrying out the experimental study, a pilot test was conducted with eight learners to determine the feasibility of the study with respect to learning task, materials, instruments, scripts, and the platform. These eight learners were divided into four pairs, and then three pairs were given their own scripts – either transactive memory, transactive discussion, or combined script – and one group, the control group, was not given a script.

This pilot study resulted in a slight modification of the learning task and materials as well as the functionality of the platform. For instance, in the pilot study, learners appeared to need more information on the farmers and location characteristics for elaborating on the learning materials. Therefore, in the actual experiment, learners were provided with more information on demographic characteristics of the farmers and geographical features of the location. Moreover, the platform was equipped with a notification of new messages from the learning partner, since in the pilot study participants complained that it was not clear exactly when a new message had been posted. Furthermore, the pilot study helped us design the problem case in such a way that it would be neither too difficult nor too easy for learners on the basis of their disciplinary backgrounds. The data from the pilot study were excluded in the final analysis.

Overall, the experimental session took about 3.5 h and consisted of four main phases with a 10-minute break between phases two and three (see Table 1). During the (1) introduction and pre-test phase, which took 35 min, individual learners received introductory explanations about the experiment for five minutes. They were then asked to complete several questionnaires on demographic variables, computer literacy, argumentation skills, prior experience with and attitude towards collaboration (30 min). The data from these questionnaires were used to ensure that randomization did in fact lead to an even distribution of participants (see the Control Measures section).

During the (2) individual phase, learners first received an introductory explanation of how to analyze the case (5 min). They were then given 5 min to read the problem case and 10 min to study a three-page summary of the theoretical text regarding SAWM and CBSM and also demographic characteristics of the farmers and the location of the case study. Learners were allowed to make notes and to keep the text and their notes during the experiment. Prior to collaboration, learners were asked to individually analyze the problem case and design an effective plan (20 min) for fostering sustainable behaviour on the basis of their own domain of expertise. More specifically, learners with an international development background were asked to design an effective plan for fostering sustainable behaviour among Nahavand farmers taking into account the concept of CBSM, whereas learners with an international land and water management background were asked to design an effective plan for fostering SAWM among Nahavand farmers. The data from this pretest served two purposes: to assess learners' prior knowledge regarding SAWM or CBSM, and to help us check for the randomization of learners in terms of prior knowledge over various conditions.

After a 10-minute break, the (3) collaborative learning phase (90 min) began. First, learners were oriented to the CSCL platform and acquainted with the procedure of the collaboration phase (10 min). Subsequently, learners were asked to discuss and support their analyses and design plans in pairs (80 min). Specifically, they were asked to analyze and discuss the same problem case as in the pretest and to jointly design an effective plan for fostering SAWM based on the concept of CBSM. This collaborative outcome served as the criteria for assessing quality of the joint problem solution plan.

During the (4) post-test and debriefing phase (45 min), learners were first asked to work on a comparable case-based assignment individually (20 min) based on what they had learned in the collaboration phase. They were asked to analyze and design an effective plan for fostering sustainable behaviour among Nahavand wheat farmers in terms of irrigation methods that could be applied for fostering SAWM as a CBSM advisor. This individual task was used for assessing the quality of the individual problem solution plan. Furthermore, learners were asked to fill out several questionnaires to assess various aspects of their satisfaction with the learning experience and its outcomes (20 min). Finally, the participants got a short debriefing for about 5 min.

Measurements, instruments, and data sources

Assessing transactive knowledge sharing during the collaborative phase

The learners' online messages during the collaborative learning phase were analyzed by means of an adapted coding scheme developed by Weinberger and Fischer (2006). Specifically, we analyzed transactive knowledge sharing by focusing on the function or social mode of messages, i.e., how learners refer to each other's messages. Every message posted during the online discussion was coded as one of the following: no reaction, externalization, acceptance, elicitation, integration, or conflict. When learners did not respond to questions (and other forms of elicitation) from their learning partners, we coded the chronologically next message as "no reaction (to learning partner)". When learners formally replied to a (mother) message of a learning partner, i.e., they hit the reply button after reading a message by their learning partner, but did not refer at all to what their learning partner had said in the (mother) message they were replying to, we coded their (daughter) message as "no reaction". When learners displayed their knowledge without reference to earlier messages, for instance when they composed the first analysis in the discussion board or typically also the first messages in a discussion thread, we coded the message as externalization. Sometimes, learners might juxtapose externalizations, i.e., reply to earlier externalizations by a further externalization. When learners asked for, or invited a reaction from their learning partners, we coded the message as elicitation. Typically, this took the form of questions. However, learners often forgot the question marks or made proposals rather than asking directly. If an elicitation was not responded to, the next message was coded as "no reaction". When learners agreed to what had been said before without any modification by repeating what had been said, we coded the message as acceptance. Learners might have taken over perspectives from their peers and built syntheses of (various) arguments and counter-arguments that learning partners had uttered before, which we coded as integration. Any rejection, denial, or negative answer/evaluation was coded as conflict. Beyond saying "No" or "I disagree", any kind of modification or replacement of what had been said before was also coded as conflict. Thus, smaller repairs and additions to a learning partner's utterances were coded as conflict. This included taking note of the phenomenon of alleviating critiques by initializing responses with phrases such as "I totally agree, but…". Several of these social modes could be found within one message. Therefore, we coded the discourse hierarchically. For example, if the message contained a conflict, the message was coded as conflict regardless of what else could be found in the message. The hierarchy was as follows: conflict, integration, elicitation, acceptance, externalization, or no reaction (see Table 2 for coding procedure and examples).

Two trained coders coded three discourse corpora in each condition to determine the reliability index of inter-rater agreement. The inter-rater agreement computed on the basis of this overlapping coding was sufficiently high (Cohen's κ=.88). Moreover, intra-coder test-retest reliability was calculated for 10 % of the discourse corpora. This resulted in identical scores in 93 % of the contributions. For each pair, we counted the sum of messages that were coded as conflict, integration, elicitation, acceptance, externalization, or no reaction as an indicator of transactive knowledge sharing. The scores on this measure were then transformed into proportions in relation to the total number of messages during the collaborative phase. In addition, we analyzed the percentage of various categories of transactive knowledge sharing for each dyad in all conditions.

Measuring domain-specific knowledge transfer (individual-to-group, group-to-individual, and shared knowledge transfer)

We operationalized knowledge transfer as an interaction between domain-specific knowledge of the individual learner and his/her partner in terms of individual-to-group, group-to-individual, and shared knowledge transfer. An expert solution for the task was used to analyze the domain-specific knowledge transfer. This expert solution included all the possible theoretical concepts of SAWM and CBSM, and their relation to the problem cases (see Noroozi et al. 2013a). The next step of the analysis involved characterizing the content of both of the problem solutions generated in the two individual phases of the study, both prior to (pre-test) and after collaboration (post-test), as well as the joint solution generated by the dyads in the collaborative phase. Learners received a score of 1 for each adequately applied theoretical concept and for relating it appropriately to the problem cases in their joint and individual problem solution plans leading to a sum score in the end. Both inter-rater agreement between two coders (Cohen's κ=.88) and intra-coder test-retest reliability for each coder for 10 % of the data (90 % identical scores) were sufficiently high.

Individual-to-group knowledge transfer

Building on Noroozi et al. (2013a), the impact that each individual learner had on the joint solution plan was estimated by the total number of his/her own individual representations that s/he managed to transfer to the joint solution plan. The indicator of individual-to-group knowledge transfer for each participant was then the sum score of all relevant and correct applications of that participant's own theoretical concepts that were transferred to the dyad's joint solution plan (see Fig. 1).

Group-to-individual knowledge transfer

Building on Noroozi et al. (2013a), the impact that participating in a dyad had on the individual learner was estimated by the total number of relevant and correct applications of a learning partner's theoretical concepts that emerged in the collaborative process and re-emerged in the individual problem solutions. The indicator of group-to-individual knowledge transfer for each participant was then the sum score of all relevant and correct t2.1 **Table 2** Coding rubric for transactive knowledge sharing by social modes

t2.2	Code	Description	Examples
t2.3	No reaction	When learners do not respond to questions (and other forms of elicitation) of their learning partners.	A: "I doubt if furrow, border strip or basin irrigation is a good system in the east part of the area due to the sandy nature of its soil. Sandy soils have a low water storage capacity and a high infiltration rate. They therefore need frequent but small irrigation applications."
t2.4		When learners formally reply to a (mother) message of a learning partner but do not refer at all to what their learning partner has said in the (mother) message they are replying to.	B: "No reply"
t2.5			A: "I think surface irrigation is a good system in the North of Nahavand since the type of soil in that area is clay with low infiltration rates."
t2.6			B: "Let's wrap up the discussion due to the time constraint."
t2.7	Externalization	When learners outline their knowledge without reference to earlier messages, for instance when they compose the first analysis in the discussion board or typically also the first messages in a discussion thread.	"I would encourage farmers to use the drip irrigation method since there is a steep slope in the area and this method could prevent runoff.-"
t2.8		When learners juxtapose externalizations, i.e. reply to earlier externalizations with an externalization.	A: "I would encourage farmers to use the drip irrigation method since there is a steep slope in the area and this method could prevent runoff."
t2.9			B: "Drip irrigation could (also) save a lot of water in this water-scarce area by preventing deep percolation, or evaporation."
t2.10	Acceptance	When learners agree to what has been said before without further elaboration.	A: "The type of crop is a very important consideration when choosing a beneficial irrigation method."
t2.11		When learners agree to what has been said before without any modification by repeating what has been said.	B: "I agree", or something similar.
t2.12			A: "The type of crop is a very important consideration when choosing a beneficial irrigation method"
t2.13			B: "We need to consider the type of products and their value in relation to the various irrigation methods used by farmers."
t2.14	Elicitation	When learners ask for or invite a reaction from their learning partners. Typically, this is done by asking questions.	"What are the possible technical problems in the area in terms of implementing the sprinkler irrigation method"?
t2.15		However, learners often forget the question marks or make proposals rather than asking directly.	"We should also talk about the external barriers for behaviour change."
t2.16	Integration	When learners adopt the perspectives of their peers and build syntheses of (various) arguments and counter-arguments that learning partners have uttered before.	A: "Farmers rarely accept the drip irrigation method due to the technical requirements for implementing it on the farm."
t2.17			B: "For the technical requirements we could provide farmers with short and long-term training sessions to teach them how to install, apply and maintain the system."
t2.18	Conflict	When learners reject, deny, or give a negative answer to/evaluation of what has been said before.	A: "I would encourage farmers to use the drip irrigation method since there is a steep slope in the area."

t2.20 **Table 2** (continued)

	Code	Description	Examples
t2.19		When learners modify or replace what has been said before.	B: "No" or "I disagree", etc.
t2.20		When learners slightly amend or add to the learning partners' utterances.	A: "I would encourage farmers to use sprinkler and drip irrigation. Because of the high capital investment required per hectare, these are mostly used for high-value cash crops, e.g. vegetables and fruit trees."
t2.21			B: "Drip irrigation could be a complete waste of water in the south of Nahavand when you take the soil minerals and toxicity into account."
t2.22			A: "Farmers would not accept a drip irrigation system due to their lack of technical knowledge."
t2.23			B: "They also would not easily accept drip irrigation due to the huge initial costs for implementing the system."
t2.24			A: "Surface irrigation is preferred if the irrigation water contains much sediment, which can clog drip or sprinkler irrigation systems."
t2.25			B: "I totally agree, but…"

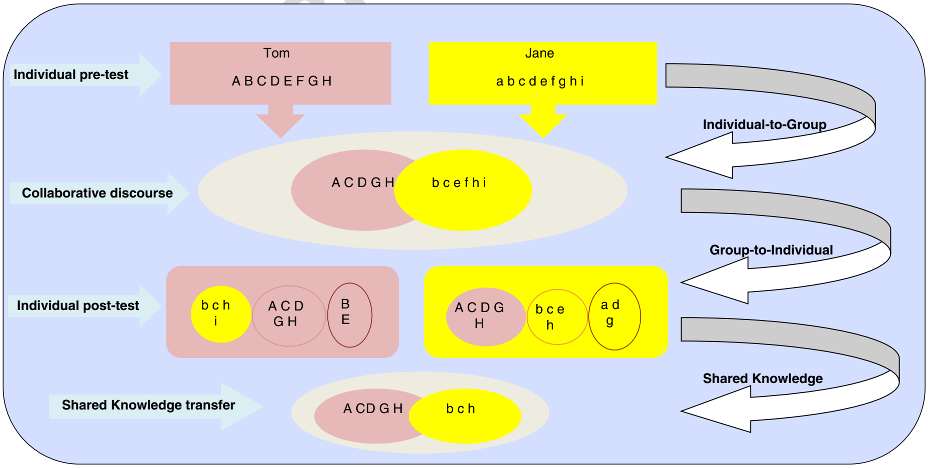

Fig. 1 A graphical representation for measuring domain-specific knowledge transfer. (*Capital letters* represent relevant and correct application of the theoretical concepts from Tom's domain of expertise. *Lower case letters* represent relevant and correct application of the theoretical concepts from Jane's domain of expertise.) Tom scores 5 and 4 on individual- to- group and group- to-individual knowledge transfer respectively. Jane scores 6 and 5 on individual- to- group and group- to-individual knowledge transfer respectively. Tom and Jane score 8 on shared knowledge transfer. Capital letters "B" and "E" and also lower case letters "a", "d", and "g" were not transferred from individual to group representations. They were, however, transferred from the learners' own individual pre-tests to their individual post-tests

applications of a learning partner's theoretical concepts that were transferred to the individual's own solution plan in the post-test (see Fig. 1).

Shared knowledge transfer

Successful collaboration depends not only on the extent to which learners (co)construct knowledge, but also the extent to which knowledge is shared by the participants in the group (Stahl and Hesse 2009). We used individual problem solution plans in the post-test to measure shared knowledge transfer between dyad members. Building on Noroozi et al. (2013a), the indicator of shared knowledge transfer for each dyad was the sum score of all relevant and correct applications of theoretical concepts in relation to the problem case, which both dyad members appropriately shared in their individual representations in the post-test (see Fischer & Mandl 2005). For example, as can be seen in Fig. 1, Tom and Jane shared eight relevant and correct applications of theoretical concepts in the post-test. Five of these concepts belong to Tom's domain of expertise and three of them belong to Jane's domain of expertise. So, the score eight was assigned for Tom's and Jane's shared knowledge transfer.

Measuring quality of joint and individual problem solution plans

The measure of group performance was operationalized as the quality of the joint problem solution plan produced by the dyad during their collaboration. Building on Noroozi et al. (2013a), the measure of individual performance was operationalized as the quality of the individual problem solution plan produced by each learner after collaboration in the post-test. In contrast to the quantitative analyses on domain-specific knowledge transfer measurements that focused on the numerical applications of the theoretical concepts in relation to the problem cases, the qualitative strategy adopted for measuring the quality of joint and individual problem solution plans was to focus on the extent to which pairs and individual learners were able to support their theoretical assumptions in relation to the case with justifiable arguments, discussions, and sound interpretations that contributed to the advancement of the problem solution plans (see Noroozi et al. 2013a, for a full description of the qualitative measurement).

Both joint and individual problem solution plans were independently rated by two expert coders on a scale ranging from "inadequate problem solution plan" to "high-quality problem solution plan". Both inter-rater agreement between two coders (Cohen's κ=.84) and intra-coder test-retest reliability for each coder for 10 % of the data (89 % identical scores) were sufficiently high. We then assigned 0 points for inadequate problem solution plans, 1 point for low quality, 2 points for rather low quality, 3 points for rather high quality, and 4 points for high-quality problem solution plans. Based on these points, we calculated the mean quality score for the joint (group values) and individual (aggregated group values) problem solution plans in all conditions.

Control measures

Various factors of a learner's background and experience have been discussed as being relevant and important in CSCL settings, such as computer literacy and prior experience with and attitude towards collaboration (see Beers et al. 2007; Noroozi et al. 2011, 2012a, b; Rummel et al. 2009). We therefore checked whether the participants were equally distributed over the four conditions for these measures.

Measurement of computer literacy

Building on Noroozi et al. (2013b), the learners were measured on computer literacy using a questionnaire with 10 items using a five-point Likert scale ranging from "almost never true" to "almost always true". The questionnaire was designed to ascertain the extent to which learners considered themselves to be skillful in terms of (a) software applications (MS Word, Excel, or other programs), (b) using the Internet for communication via e-mail, Chat, Blackboard, SharePoint, Web 2.0 tools, and other social media. Furthermore, we asked learners to rate themselves in terms of general computer skills on a scale of one to five. The reliability coefficient was sufficiently high (Cronbach α=.83).

Measurement of prior experience with and attitude towards collaboration

Building on Noroozi et al. (2013b), the learners were measured on these collaboration variables using a questionnaire with 25 items using a five-point Likert scale ranging from "almost never true" to "almost always true". Nine items of this questionnaire asked learners to ascertain the extent to which they had prior experience with collaboration. For example, they were asked to specify their collaboration experience by choosing from a list of alternatives (school, workplace, etc.) and also to rate themselves on general prior experience with collaboration. Sixteen items of this questionnaire were aimed to ascertain learners' attitudes towards collaboration. For example, they were asked to rate themselves on statements such as "collaboration fosters learning", "learning should involve social negotiation", "one learns more while performing tasks in a collaborative manner than individually", etc. The reliability coefficient was sufficient for both prior experience with (Cronbach α=.79) and attitudes towards collaboration (Cronbach α=.82).

Unit of analysis

The unit of analysis, either at the individual or dyad level, depended on the research question addressed. We used single individual as the unit of analysis to check for the equal distribution of the learners over the four conditions in terms of prior knowledge, number of passed courses, computer literacy, prior experience with collaboration, and learners' attitudes towards collaboration. We used the dyads (group values) as the unit of analysis for the research question 1, part of research question 2 addressing shared knowledge transfer, and for part of research question 3 regarding the quality of joint problem solution plans which are directed to the discourse and to the collaborative solution of the learning task. In contrast, the individual as the unit of analysis (aggregated group values) was used to measure individual-to-group and group-to-individual knowledge transfer for research question 2, and the part of research question 3 addressing the quality of individual problem solution plans (see Kapur 2008; Fischer et al. 2002; Raudenbush and Bryk 2002; Noroozi et al. 2013a, b). Although these measurements were taken individually, the individual scores within each dyad were not independent observations due to the collaboration that preceded it (Kapur 2008; Raudenbush and Bryk 2002) and also the design of the platform, which supported group rather than individual work (Stahl 2010, 2011a). Therefore, we used aggregated group values for these measurements.

Data analysis and statistical tests

The scores of four pairs of learners (one pair in each condition) were excluded from the analyses due to the limited number of their contributions. Therefore, for data analyses, 112 learners (14 pairs in each of the four conditions) were included in the study. ANOVA tests were used to compare the prior knowledge, number of passed courses, computer literacy, prior experience with collaboration, and learners' attitudes towards collaboration among learners. MANOVA was used to analyze the proportion of various types of messages in terms of transactive knowledge sharing: for these tests, the absolute scores were transformed into proportions. Univariate analyses were used as a post-hoc analysis to examine statistical differences among the conditions. MANOVA was conducted to analyze domain-specific knowledge transfer measures. Univariate analyses for each of these knowledge transfer measures (individual-to-group, group-to-individual, and shared knowledge transfer measures) were then conducted as follow-up tests to the MANOVA. MANOVA was again conducted to compare mean differences between learners in terms of quality of problem solution plans. Univariate analyses for each of these problem solution plans (joint and individual problem solution plans) were then conducted as follow-up tests to the MANOVA. Furthermore, simple effects tests were conducted as follow-up tests only when the interaction was significant.

Results

Learning prerequisites and control measures

The learners with an international development studies background in the four conditions showed no differences with respect to prior knowledge, $F(3, 52)=.45$, $p>.2$ ($M=10.93$, $SD=2.72$, $Max=16$, $Min=7$), and number of passed courses ($M=3.78$, $SD=1.61$, $Max=7$, $Min=2$) on CBSM and related topics, $F(3, 52)=.23$, $p>.2$. The same was true for the learners with an international land and water management studies background regarding prior knowledge, $F(3, 52)=.42$, $p>.2$ ($M=7.70$, $SD=2.77$, $Max=14$, $Min=2$), and number of passed courses ($M=3.44$, $SD=1.09$, $Max=6$, $Min=2$) on SAWM and related topics, $F(3, 52)=.56$, $p>.2$. These results show that the random assignment of learners to the four conditions led to no significant differences in prior knowledge or background requirements.

Furthermore, learners in the four conditions showed no differences regarding the mean scores of computer literacy, $F(3, 108)=.67$, $p>.2$, and prior experience with collaboration, $F(3, 108)=.76$, $p>.2$. The same was true for the learners' attitudes towards collaboration, $F(3, 108)=.91$, $p>.2$. These results show that the random assignment of learners to the four conditions led to no significant differences in terms of learners' individual prerequisites.

Descriptive information for the script effects on various dependent variables

Table 3 shows the script effects for various experimental conditions with regard to all of the dependent variables in this study, including the number and quality of student messages during the collaborative phase in terms of transactive knowledge sharing (conflict, integration, elicitation, acceptance, externalization, no reaction), domain-specific knowledge transfer (individual-to-group, group-to-individual, and shared knowledge transfer measures), as well as quality of problem solution plans (joint and individual). In total, participants with the transactive memory or discussion script separately produced a higher quality of transactive knowledge sharing during discourse, constructed and transferred more domain-specific knowledge, and achieved a higher quality of joint and individual problem solution plans than participants in the combined script and control group conditions. In other words, when both scripts were offered at the same time, a lower quality of messages was exchanged, less t3.1 **Table 3** Qualitative descriptions of various dependent variables for each of the four conditions: means (M) and standard deviations (SD)

	Dependent variables	Items	Control group (CG)		Transactive memory script (TMS)		Transactive discussion script (TDS)		Both scripts (BS)		Significant at .05 level	Significant at .01 level
t3.3			M	SD	M	SD	M	SD	M	SD		
t3.4	Number of messages	Number of messages	23.71	5.78	26.64	4.48	27.86	4.60	20.14	4.74		
t3.5	Transactive knowledge sharing	No reaction (%)	4.71	6.03	4.30	5.12	1.04	2.16	12.93	15.17	BS>TDS	BS>TMS
t3.6		Externalization (%)	27.68	7.08	44.35	11.63	18.12	9.01	36.03	10.36	CG>TDS	TMS>CG; TMS>TDS; BS>CG; BS>TDS; BS>TDS
t3.7		Acceptance (%)	10.92	5.15	6.67	5.58	6.81	3.59	11.76	8.81	CG>TMS; CG>TDS; BS>TMS; BS>TDS	
t3.8		Elicitation (%)	14.68	5.43	27.99	7.26	18.75	7.78	21.47	13.41	TMS>BS	TMS>CG; TDS>TDS
t3.9		Integration (%)	10.85	8.58	12.79	6.59	29.97	9.23	12.02	11.83	TMS>CG	TDS>TMS; TDS>CG; TDS>BS
t3.10		Conflict (%)	1.56	2.68	3.89	4.72	11.31	5.09	5.48	8.65	BS>CG	TDS>CG; TDS>TMS; TDS>BS
t3.11	Knowledge transfer measures	Individual-to-group	15.14	3.86	16.64	3.77	18.64	3.23	12.64	4.18	TDS>CG	TMS>BS; TDS>BS
t3.12		Group-to-individual	3.93	1.07	6.14	1.70	5.93	2.09	3.14	1.61		TMS>CG; TMS>BS; TDS>CG; TDS>BS
t3.13		Shared knowledge	7.50	1.95	11.79	3.12	11.36	3.98	6.00	3.23		TMS>CG; TMS>BS; TDS>CG; TDS>BS
t3.14	Quality of solution plans	Joint solution plan	2.21	.58	3	.78	3.36	.84	1.93	.73		TMS>CG; TMS>BS; TDS>CG; TDS>BS
t3.15		Individual solution plan	2.43	.43	2.93	.76	3.14	.99	2.00	.62	TDS>CG	TMS>BS; TDS>BS

domain-specific knowledge was transferred, and lower quality of problem solution plans was produced than when these scripts were offered separately (see Table 3, for the statistical information).

Results for research question 1

The first research question was: To what extent is the quality of student messages during the collaborative phase in terms of transactive knowledge sharing affected by a transactive memory script, transactive discussion script, and their combination in a multidisciplinary CSCL setting? In this section we will first present the findings on the overall quantity and quality of student messages during the collaborative phase in terms of transactive knowledge sharing. Next, we will present results for various categories of the transactive knowledge sharing (conflict, integration, elicitation, acceptance, externalization, no reaction) according to the scheme described in the method section.

Number of messages during collaborative phase

Learners showed significant differences with respect to the number of messages contributed in the collaborative phase, $F(3, 52)=6.80$, $p<.01$, $\eta^2=.28$. The main effect of the transactive memory script on the total number of messages contributed to the discourse was just below the significant level, $F(1, 52)=3.30$, $p=.08$, $\eta^2=.06$, with scripted learners ($M=23.40$) scoring about the same as unscripted learners ($M=25.79$). This main effect was not significant for the transactive discussion script, $F(1, 52)=.80$, $p=.37$, with scripted learners ($M=24.00$) scoring about the same as unscripted learners ($M=25.18$). However, the interaction effect, $F(1, 52)=16.32$, $p<.01$, $\eta^2=.24$, was significant. For participants who received the transactive memory script, a higher number of messages was authored when the transactive discussion script was not offered than when it was offered, $F(1, 52)=12.17$, $p<.01$, $\eta^2=.19$. For participants who did not receive the transactive memory script, a higher number of messages was authored when the transactive discussion script was offered than when it was not offered, $F(1, 52)=4.94$, $p<.05$, $\eta^2=.90$. For participants who received the transactive discussion script, a higher number of messages was authored when the transactive memory script was not offered than when it was offered, $F(1, 52)=17.14$, $p<.01$, $\eta^2=.25$. For participants who did not receive the transactive discussion script, the transactive memory script had no effect, $F(1, 52)=2.47$, $p=.12$.

Quality of student messages during the collaborative phase in terms of transactive knowledge sharing

Learners in the four conditions showed significant differences with respect to the overall quality of messages contributed during the collaborative phase in terms of transactive knowledge sharing. Specifically, the main effect of the transactive memory script on transactive knowledge sharing was significant, *Wilks'* $\lambda=.20$, $F(3, 52)=30.76$, $p<.01$, $\eta^2=.80$. The same was true for the transactive discussion script, *Wilks'* $\lambda=.45$, $F(3, 52)=9.46$, $p<.01$, $\eta^2=.55$. Furthermore, the interaction effect, *Wilks'* $\lambda=.43$, $F(3, 52)=10.47$, $p<.01$, $\eta^2=.57$, was significant, indicating that the script effects were not the same regarding transactive knowledge sharing.

Concerning no reaction to messages, the main effect of the transactive memory script was significant, $F(1, 52)=4.26$, $p<.05$, $\eta^2=.08$, with scripted learners ($M=.08$) scoring higher than unscripted learners ($M=.04$). This main effect was not significant for the transactive discussion script, $F(1, 52)=.48$, $p=.49$, with scripted learners ($M=.07$) scoring about the same as unscripted learners ($M=.05$). The interaction effect was significant, $F(1, 52)=8.61$, $p<.01$, $\eta^2=.14$. For participants who received the transactive memory script, a higher proportion of "no reaction messages" was identified when the transactive discussion script was offered than when it was not offered, $F(1, 52)=6.59$, $p<.05$, $\eta^2=.11$. For participants who did not receive the transactive memory script, the transactive discussion script had no effect, $F(1, 52)=2.50$, $p=.12$. For participants who received the transactive discussion script, a higher proportion of "no reaction messages" was identified when the transactive memory script was offered than when it was not offered, $F(1, 52)=12.49$, $p<.01$, $\eta^2=.19$. For participants who did not receive the transactive discussion script, the transactive memory script had no effect, $F(1, 52)=.38$, $p=.54$.

Regarding knowledge externalization, the main effect of the transactive memory script was significant, $F(1, 52)=53.29$, $p<.01$, $\eta^2=.51$. Learners with the transactive memory script ($M=.39$) produced a higher proportion of "knowledge externalization messages" than unscripted learners ($M=.22$) during discourse. The same was true for the transactive discussion script, $F(1, 52)=7.70$, $p<.01$, $\eta^2=.13$. Learners with the transactive discussion script ($M=.27$) produced a higher proportion of messages for knowledge externalization than unscripted learners ($M=.34$) during discourse. However, no interaction effect, $F(1, 52)=.11$, $p=.76$, was found.

Concerning acceptance, the main effect of the transactive memory script was not significant, $F(1, 52)=.01$, $p=.96$, with scripted learners ($M=.09$) scoring the same as unscripted learners ($M=.09$). This main effect was also not significant for the transactive discussion script, $F(1, 52)=.01$, $p=.95$, with scripted learners ($M=.09$) scoring the same as unscripted learners ($M=.09$). However, the interaction effect, $F(1, 52)=10.03$, $p<.01$, $\eta^2=.16$, was significant. For participants who received the transactive memory script, a higher proportion of "acceptance messages" was produced when the transactive discussion script was offered than when it was not offered, $F(1, 52)=4.80$, $p<.05$, $\eta^2=.09$. For participants who did not receive the transactive memory script, a higher proportion of "acceptance messages" was produced when the transactive discussion script was not offered than when it was offered, $F(1, 52)=5.23$, $p<.05$, $\eta^2=.09$. For participants who received the transactive discussion script, a higher proportion of "acceptance messages" was identified when the transactive memory script was offered than when it was not offered, $F(1, 52)=5.18$, $p<.05$, $\eta^2=.09$. For participants who did not receive the transactive discussion script, a higher proportion of "acceptance messages" was identified when the transactive memory script was not offered than when it was offered, $F(1, 52)=4.85$, $p<.05$, $\eta^2=.08$.

Concerning knowledge elicitation, the main effect of the transactive memory script was significant, $F(1, 52)=11.84$, $p<.01$, $\eta^2=.16$, with scripted learners ($M=.26$) scoring higher than unscripted learners ($M=.17$). This main effect was not significant for the transactive discussion script, $F(1, 52)=1.00$, $p=.32$, with scripted learners ($M=.20$) scoring about the same as unscripted learners ($M=.23$). The interaction effect, $F(1, 52)=5.52$, $p<.05$, $\eta^2=.10$, was significant. For participants who received the transactive memory script, a higher proportion of "elicitation messages" was produced when the transactive discussion script was not offered than when it was offered, $F(1, 52)=5.60$, $p<.05$, $\eta^2=.10$. For participants who did not receive the transactive memory script, the transactive discussion script had no effect, $F(1, 52)=.91$, $p=.34$. For participants who received the transactive discussion script, the transactive memory script had no effect, $F(1, 52)=.60$, $p=.44$. For participants who did not receive the transactive discussion script, a higher proportion of "elicitation messages" was identified when the transactive memory script was offered than when it was not offered, $F(1, 52)=16.76$, $p<.01$, $\eta^2=.24$.

Regarding knowledge integration, the main effect of the transactive memory script was significant, $F(1, 52)=5.74$, $p<.05$, $\eta^2=.10$, with scripted learners ($M=.13$) scoring lower than unscripted learners ($M=.19$). This main effect was significant for the transactive discussion script, $F(1, 52)=19.57$, $p<.01$, $\eta^2=.27$, with scripted learners ($M=.21$) scoring higher than unscripted learners ($M=.11$). The interaction effect, $F(1, 52)=28.20$, $p<.01$, $\eta^2=.35$, was also significant. For participants who received the transactive memory script, the transactive discussion script had no effect, $F(1, 52)=.39$, $p=.53$. For participants who did not receive the transactive memory script, a higher proportion of "integration messages" was identified when the transactive discussion script was offered than when it was not offered, $F(1, 52)=47.38$, $p<.01$, $\eta^2=.48$. For participants who received the transactive discussion script, a higher proportion of "integration messages" was produced when the transactive memory script was not offered than when it was offered, $F(1, 52)=29.71$, $p<.01$, $\eta^2=.36$. For participants who did not receive the transactive discussion script, a higher proportion of "integration messages" was produced when the transactive memory script was offered than when it was not offered, $F(1, 52)=4.24$, $p<.05$, $\eta^2=.08$.

Concerning conflict-oriented knowledge building, the main effect of the transactive memory script was not significant, $F(1, 52)=1.73$, $p=.19$, with scripted learners ($M=.04$) scoring about the same as unscripted learners ($M=.06$). However, this main effect was significant for the transactive discussion script, $F(1, 52)=19.26$, $p<.01$, $\eta^2=.27$, with scripted learners ($M=.08$) scoring higher than unscripted learners ($M=.02$). The interaction effect, $F(1, 52)=7.45$, $p<.01$, $\eta^2=.13$, was also significant. For participants who received the transactive memory script, the transactive discussion script had no effect, $F(1, 52)=1.37$, $p=.27$. For participants who did not receive the transactive memory script, a higher proportion of "conflict-oriented messages" was produced when the transactive discussion script was offered than when it was not offered, $F(1, 52)=25.33$, $p<.01$, $\eta^2=.33$. For participants who received the transactive discussion script, a higher "conflict-oriented messages" was produced when the transactive memory script was not offered than when it was offered, $F(1, 52)=8.19$, $p<.01$, $\eta^2=.14$. For participants who did not receive the transactive discussion script, the transactive memory script had no effect, $F(1, 52)=.10$, $p=.32$.

Results for research question 2

The second research question was: To what extent is the domain-specific knowledge transfer affected by a transactive memory script, transactive discussion scrip, and their combination in a multidisciplinary CSCL setting? In this section we will first present the findings on the overall domain-specific knowledge transfer. Next we will present the findings separately on individual-to-group, group-to-individual, and shared knowledge transfer measures.

Overall domain-specific knowledge transfer

The main effect of the transactive memory script on the overall domain-specific knowledge transfer was not significant, *Wilks'* $\lambda=.91$, $F(3, 52)=1.65$, $p=.19$. The same was true for the transactive discussion script, *Wilks'* $\lambda=.97$, $F(3, 52)=.43$, $p=.73$. The interaction effect, *Wilks'* $\lambda=.55$, $F(3, 52)=13.77$, $p<.01$, $\eta^2=.45$, was significant, indicating that the script effects were not the same regarding overall domain-specific knowledge transfer.

Individual-to-group knowledge transfer

The main effect of the transactive memory script on individual-to-group knowledge transfer was significant, $F(1, 52)=4.97$, $p<.05$, $\eta^2=.09$, with scripted learners ($M=14.64$) scoring lower than unscripted learners ($M=16.90$). In other words, a script that organized learners into roles by their expertise resulted in collaborative solutions with more ideas from each partner. This main effect was not significant for the transactive discussion script, $F(1, 52)=.06$, $p=.80$, with scripted learners ($M=15.64$) scoring about the same as unscripted learners ($M=15.89$). The interaction effect, $F(1, 52)=13.81$, $p<.01$, $\eta^2=.21$, was significant. For participants who received the transactive memory script, a higher "individual-to-group" knowledge transfer was achieved when the transactive discussion script was not offered than when it was offered, $F(1, 52)=7.86$, $p<.01$, $\eta^2=.13$. For participants who did not receive the transactive memory script, a higher "individual-to-group" knowledge transfer was achieved when the transactive discussion script was offered than when it was not offered, $F(1, 52)=6.02$, $p<.05$, $\eta^2=.10$. For participants who received the transactive discussion script, a higher "individual-to-group" knowledge transfer was achieved when the transactive memory script was not offered than when it was offered, $F(1, 52)=17.68$, $p<.01$, $\eta^2=.25$. For participants who did not receive the transactive discussion script, the transactive memory script had no effect, $F(1, 52)=1.10$, $p=.30$ (see Fig. 2).

Group-to-individual knowledge transfer

The main effect of the transactive memory script on group-to-individual knowledge transfer was not significant, $F(1, 52)=.41$, $p=.52$, with scripted learners ($M=4.64$) scoring about the same as unscripted learners ($M=4.93$). The same was true for the transactive discussion script, $F(1, 52)=1.27$, $p=.26$, with scripted learners ($M=4.54$) scoring about the same as unscripted learners ($M=5.04$). However, the interaction effect, $F(1, 52)=31.75$, $p<.01$, $\eta^2=.38$, was significant. For participants who received the transactive memory script, a higher "group-to-individual" knowledge transfer was achieved when the transactive

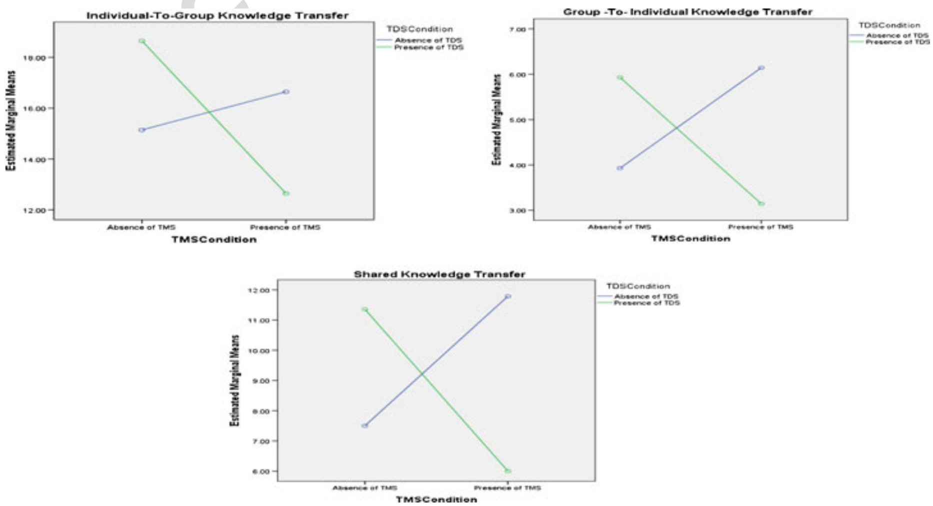

Fig. 2 A graphical representation of the interaction effects of the scripts regarding domain- specific knowledge transfer (individual- to- group, group- to-individual and shared knowledge transfer measures)

discussion script was not offered than when it was offered, $F(1, 52)=22.86$, $p<.01$, $\eta^2=.30$. For participants who did not receive the transactive memory script, a higher "group-to-individual" knowledge transfer was achieved when the transactive discussion script was offered than when it was not offered, $F(1, 52)=10.16$, $p<.01$, $\eta^2=.16$. For participants who received the transactive discussion script, a higher "group-to-individual" knowledge transfer was achieved when the transactive memory script was not offered than when it was offered, $F(1, 52)=19.71$, $p<.01$, $\eta^2=.27$. For participants who did not receive the transactive discussion script, a higher "group-to-individual" knowledge transfer was achieved when the transactive memory script was offered than when it was not offered, $F(1, 52)=12.46$, $p<.01$, $\eta^2=.19$. In total, with no script or both scripts at the same time, individual solutions reused fewer ideas from the collaborative solution than with transactive memory or discussion scripts offered separately (see Fig. 2).

Shared knowledge transfer

The main effect of the transactive memory script on shared knowledge transfer was not significant, $F(1, 52)=.40$, $p=.53$, with scripted learners ($M=8.90$) scoring about the same as unscripted learners ($M=9.43$). The same was true for the transactive discussion script, $F(1, 52)=1.31$, $p=.26$., with scripted learners ($M=8.68$) scoring about the same as unscripted learners ($M=9.64$). However, the interaction effect, $F(1, 52)=32.73$, $p<.01$, $\eta^2=.39$, was significant. For participants who received the transactive memory script, a higher "shared knowledge" transfer was achieved when the transactive discussion script was not offered than when it was offered, $F(1, 52)=23.56$, $p<.01$, $\eta^2=.31$. For participants who did not receive the transactive memory script, a higher "shared knowledge" transfer was achieved when the transactive discussion script was offered than when it was not offered, $F(1, 52)=10.47$, $p<.01$, $\eta^2=.17$. For participants who received the transactive discussion script, a higher "shared knowledge" transfer was achieved when the transactive memory script was not offered than when it was offered, $F(1, 52)=20.20$, $p<.01$, $\eta^2=.28$. For participants who did not receive the transactive discussion script, a higher "shared knowledge" transfer was achieved when the transactive memory script was offered than when it was not offered, $F(1, 52)=12.93$, $p<.01$, $\eta^2=.20$ (see Fig. 2).

Results for research question 3

The third research question was: To what extent is the quality of joint and individual problem solution plans affected by a transactive memory script, transactive discussion scrip, and their combination in a multidisciplinary CSCL setting? In this section we will first present the findings on the overall quality of problem solution plans. Next, we will present separate results on the quality of joint and individual problem solution plans (see Fig. 3).

Overall quality of problem solution plans

The main effect of the transactive memory script on overall quality of problem solution plans was not significant, *Wilks'* $\lambda=.94$, $F(3, 52)=1.66$, $p=.20$. The same was true for the transactive discussion script, *Wilks'* $\lambda=.98$, $F(3, 52)=.71$, $p=.74$. However, the interaction effect, *Wilks'* $\lambda=.61$, $F(3, 52)=16.00$, $p<.01$, $\eta^2=.39$, was significant, indicating that the script effects were not the same regarding overall quality of problem solution plans.

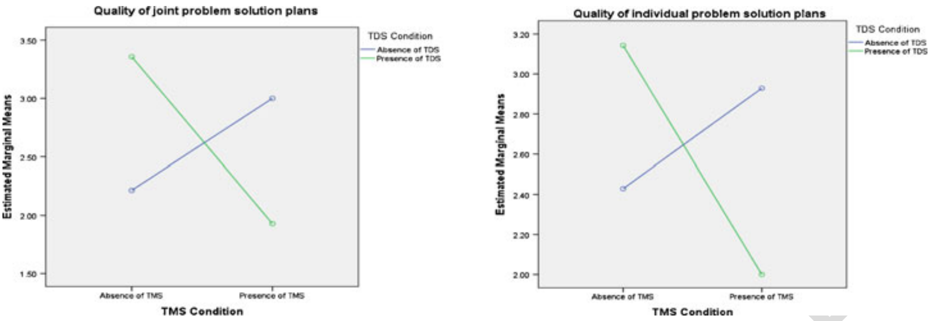

Fig. 3 A graphical representation of the interaction effects of the scripts regarding quality of joint and individual problem solution plans

Quality of joint problem solution plans

The main effect of the transactive memory script on quality of joint problem solution plans was not significant, $F(1, 52)=2.64$, $p=.11$, with scripted learners ($M=2.46$) scoring about the same as unscripted learners ($M=2.79$). This was also true for the transactive discussion script, $F(1, 52)=.03$, $p=.86$, with scripted learners ($M=2.64$) scoring about the same as unscripted learners ($M=2.61$). However, the interaction effect, $F(1, 52)=31.31$, $p<.01$, $\eta^2=.38$, was significant. For participants who received the transactive memory script, a higher quality of joint problem solution plans was achieved when the transactive discussion script was not offered than when it was offered, $F(1, 52)=14.66$, $p<.01$, $\eta^2=.22$. For participants who did not receive the transactive memory script, a higher quality of joint problem solution plans was achieved when the transactive discussion script was offered than when it was not offered, $F(1, 52)=16.68$, $p<.01$, $\eta^2=.24$. For participants who received the transactive discussion script, a higher quality of joint problem solution plans was achieved when the transactive memory script was not offered than when it was offered, $F(1, 52)=26.06$, $p<.01$, $\eta^2=.33$. For participants who did not receive the transactive discussion script, a higher quality of joint problem solution plans was achieved when the transactive memory script was offered than when it was not offered, $F(1, 52)=7.88$, $p<.01$, $\eta^2=.13$ (see Fig. 3).

Quality of individual problem solution plans

The main effect of the transactive memory script on quality of individual problem solution plans was not significant, $F(1, 52)=2.71$, $p=.11$, with scripted learners ($M=2.46$) scoring about the same as unscripted learners ($M=2.79$). The same was true for the transactive discussion script, $F(1, 52)=.30$, $p=.58$, with scripted learners ($M=2.57$) scoring about the same as unscripted learners ($M=2.68$). However, the interaction effect, $F(1, 52)=17.82$, $p<.01$, $\eta^2=.26$, was significant. For participants who received the transactive memory script, a higher quality of individual problem solution plans was achieved when the transactive discussion script was not offered than when it was offered, $F(1, 52)=11.38$, $p<.01$, $\eta^2=.18$. For participants who did not receive the transactive memory script, a higher quality of individual problem solution plans was achieved when the transactive discussion script was offered than when it was not offered, $F(1, 52)=6.74$, $p<.05$, $\eta^2=.12$. For participants who received the transactive discussion script, a higher quality of individual problem solution plans was achieved when the transactive memory script was not offered than when it was offered, $F(1, 52)=17.24$, $p<.01$, $\eta^2=.25$. For participants who did not receive the transactive discussion script, the transactive memory script had no effect, $F(1, 52)=3.30$, $p=.07$ (see Fig. 3).

Discussion

We found interaction effects for the transactive memory and discussion scripts on transactive knowledge sharing and transfer, as well as for the quality of the joint and individual problem solution plans in a multidisciplinary CSCL environment. This means that transactive memory and discussion scripts separately, but not in combination, positively impacted the targeted dependent variables in this study (see Noroozi et al. 2013a, b). More specifically, the transactive memory or discussion script conditions separately led to higher levels of transactive knowledge sharing and transfer, as well as a higher quality of joint and individual problem solution plans, than combined script and control group conditions. In the following paragraphs, we discuss how the transactive memory and discussion scripts separately facilitated problem-solving in a multidisciplinary CSCL setting and why offering the two scripts together was not beneficial.

Regarding the transactive memory script, following step-by-step guidelines and instructions embedded in the platform for each process of the TMS (encoding, storage, retrieval) helped learners to quickly become aware of their learning partners' expertise, to coordinate the collaborative learning activities by assigning and sharing task responsibilities, and finally to retrieve needed information from the learning partner with the appropriate specialization during the collaborative phase (Noroozi et al. 2013a; Rulke and Rau 2000; Wegner 1987). Formation of a collaboratively shared system for encoding, storage, and retrieving knowledge in the dyad fosters the integrative usage of information based on a heightened awareness of distributed knowledge resources, which is beneficial for transactions of unshared information in the forms of elicitation (e.g., asking questions to receive information from learning partners) and externalization (e.g., giving explanations based on the partner's expertise) during collaborative discussion (Rummel and Spada 2005; Rummel et al. 2009).

These transactions amounted to a successful exchange of unshared information between dyad members in a collaborative problem-solving setting (Weinberger et al. 2005, 2007; King 1999). Since elicitation could lead to externalization of information and vice versa (Weinberger et al. 2005, 2007), scripted learners were able to pool and process more unshared information resulting in facilitation of transactive knowledge sharing in terms of knowledge externalization and elicitation. Transactions of unshared information were followed by elaboration on and integration of one another's perspectives and ideas (see Noroozi et al. 2013a). This allowed participants to gain knowledge about their partner's domain expertise (Dillenbourg 1999) that could also be applied for designing similar problem solution plans in the subsequent individual learning task. Scripted learners were better able to externalize their own information for the learning partner and elicit information from the learning partner, resulting in the transfer of theoretical concepts from individual to dyad and from dyad representation into their individual post-test representations. Furthermore, in collaborative learning, groups whose members are aware of one another's knowledge and expertise develop a shared understanding of who knows what in the group (Wegner 1987) and thus perform better than groups whose members do not possess such knowledge (e.g., Moreland et al. 1998; Moreland and Argote 2003).

The significance of shared knowledge for collaborative learning activities especially among heterogonous groups of learners has been widely acknowledged in the scientific literature (see Hollingshead 2000; Liang et al. 1995) since learners typically influence one another when learning together (e.g., De Lisi and Golbeck 1999). Accordingly, the findings of this study corroborate other research results showing a positive impact of developing a collaboratively shared system for encoding, storage, and retrieving knowledge on performance in collaborative problem-solving settings (e.g., Stasser et al. 1995; Liang et al. 1995; Moreland et al. 1996). Furthermore, externalization of one's own knowledge and elicitation of a learning partner's knowledge have been regarded as important for improving learning performance (Fischer et al. 2002; King 1999; Rosenshine et al. 1996; Rummel et al. 2009; Teasley 1995).

Regarding the transactive discussion script, following step-by-step guidelines and instructions embedded in the platform for collaborative discussion (argumentation analysis, feedback analysis, extension of the argument and construction of argumentation sequences) helped learners to elaborate on and integrate one another's perspectives and ideas on the basis of the reasoning of peers before reaching consensus during the collaborative phase (see Noroozi et al. 2013b). Specifically, scripted learners were able to engage in deep cognitive processing for learning and discovering complementary knowledge of the learning partner in order to jointly accomplish the learning task. The various prompts in the transactive discussion script helped the dyads avoid quick consensus building that may result in a division of labor/task in what can be called "cooperation" in contrast to "collaboration" (Dillenbourg 1999, p. 8). In cooperation, learning partners typically split the task, and individually take responsibility for part of the task based on their expertise and then assemble the partial results into the final output (Dillenbourg 1999).

In the current study, unscripted learners took advantage of the knowledge of their learning partners only in a cooperative manner for accomplishing the learning task, rather than collaborating to learn and gain in-depth knowledge about each other's domain expertise (see Dillenbourg 1999). As a result, unscripted learners may have avoided engaging in critical and transactive discussions and immediately accepted their learning partners' contributions without further discussion. In contrast, scripted learners used their meta-knowledge in a collaborative rather than cooperative manner by elaborating on the learning material, integrating and synthesizing one another's perspectives and ideas in order to jointly make sense of the learning task (Fischer et al. 2002; Nastasi and Clements 1992; Schoor and Bannert 2011; Weinberger and Fischer 2006). For successful collaboration, it is important that individuals contribute to the joint product (in a cooperative manner), but also that all group members understand these contributions and realize what is taking place at the group level (in a collaborative manner) (Stahl 2011a).

Scripted learners were thus better able to paraphrase, criticize, ask clarifying/extension questions, give counterarguments, and propose an integration of arguments in response to each message that had been posted by the learning partner until they reached consensus and indicated agreement on the solutions (see Noroozi et al. 2013a). The transactive discussion script appeared to facilitate transactive knowledge sharing in terms of integration and conflict-oriented consensus building. Due to the integrative usage of information for clarification and/or elaboration of the learning material, scripted learners were able to transfer their own domain expertise to their dyads and from their dyads to their individual representations in the post-test. Furthermore, analysing their learning partners' argument(s), constructing arguments that relate to already-externalized arguments, and engaging in sequential argumentation to extend their arguments, along with feedback provided by their partners, helped scripted learners to reason based on the reasoning of their learning partners and engage in critical and constructive discussions and argumentations. When learners engage in more transactive discussions and argumentations, they benefit to a greater extent from the external memories available, e.g., contributions of their learning partners (e.g., Teasley 1997; Weinberger et al. 2005, 2007). In the current study the scripted learners demonstrated a higher level of integration of concepts acquired in their own studies with newly acquired concepts from their partners in their joint and individual solution plans.

In terms of interaction effects, offering both transactive memory and discussion scripts at the same time hindered transactive knowledge sharing and transfer, as well as the quality of joint and individual problem solution plans. This is striking since individual implementation of these scripts had a positive impact on various aspects of transactive knowledge sharing and transfer, as well as on the quality of problem solution plans. The transactive memory script facilitated learning by coordination of the distributed knowledge in the dyad, whereas the transactive discussion script facilitated learning by fostering transactive discussion and argumentation during the collaborative phase. It was expected that when used in concert, these two types of scripts would retain their individual positive effects; and no interaction effect was expected. Possible explanations for the negative interaction effect observed include the effects of “over-scripting”, the short duration of the study and its multidisciplinary context.

With respect to over-scripting, limiting students’ degrees of freedom may negatively impact their learning processes and outcomes, particularly in CSCL settings. Indeed, previous studies have questioned the use of overly detailed scripts in CSCL environments (Dillenbourg 2002; Jermann and Dillenbourg 2003; Tchounikine 2008; Weinberger and Fischer 2006). The results of these publications suggest that overly rigid scripts may inhibit and spoil the richness of natural interaction between learners during collaborative learning (Dillenbourg and Tchounikine 2007).

Following Dillenbourg (2002), in the current study when the scripts were combined, learners may have allocated a considerable proportion of their activities to the “syntax” of the instructions (i.e. various sub-tasks imposed by scripts, steps and labour roles) rather than the “semantics” (the actual collaboration with the aim of learning from one another). This could have led the script components and elements to become requirements for fulfilling the learning task rather than promoting collaboration with the aim of learning (see Onrubia and Engel 2012).

Due to the multidisciplinary nature of the learning task studied here, the learners needed the complementary expertise of their partners in each dyad in order to jointly make sense of the learning task and to design a joint problem solution plan during the collaborative learning task, which lasted only 80 min. Due to the time constraints set by this study, students who were offered both scripts may have felt the need to choose between them. There was, therefore, a possibility for a trade-off between coordination of the distributed task (transactive memory script) and collaborative discussion and argumentation (transactive discussion script). These dyads thus seemed to focus more on following the guidelines and the procedures imposed by the combined scripts than on coordination of the learning task and engaging in collaborative discussions and argumentation in order to jointly make sense of the learning task and to design a joint problem solution plan.

Conclusion, implications, limitations and suggestions for future research

Implementation of a transactive memory script appeared to facilitate transactive knowledge sharing in terms of externalization of one’s own knowledge and elicitation of a learning partner’s knowledge. The transactive memory script facilitated the transfer of domain-specific knowledge (individual-to-group, group-to-individual, and shared knowledge transfer), which in turn resulted in higher-quality learning demonstrated in both joint and individual problem solution plans. Implementation of a transactive discussion script also appeared to facilitate transactive knowledge sharing in terms of integration and conflict-oriented consensus building. Furthermore, the transactive discussion script facilitated the transfer of domain-specific knowledge (individual-to-group, group-to-individual, and shared knowledge transfer), which in turn resulted in higher-quality learning demonstrated in both joint and individual problem solution plans. However, offering transactive memory and discussion scripts at the same time hindered transactive knowledge sharing and transfer, as well as the quality of joint and individual problem solution plans. This failure of the two scripts when offered in concert could be due to the effects of over-scripting, the short study duration and the multidisciplinary context, or some combination of these three factors.

The results presented in this study should be interpreted with some caution. First, this study was conducted in a controlled laboratory setting, which entails specific advantages and disadvantages. The experimental setting provided us with the opportunity to carefully control for individual learners' characteristics and rule out many alternative explanations for the differences found. Due to the authenticity of the multidisciplinary learning scenario being part of the standard curriculum as they are required for solving these kinds of complex tasks, we assume that these effects could be replicated in the standard curricular educational settings. This is an empirical question, however, since collaborative learning in online environments is often difficult to be realized especially in ad-hoc contexts when learners embark on collaborative experiences who have not worked together before (see Häkkinen 2002; Häkkinen et al. 2004, 2010). We therefore suggest that the specific conditions, corresponding effects and learner perceptions of such a scripted environment in a multidisciplinary class be further investigated. The interaction effects in particular should be examined in future research with similar types of CSCL scripts and learning task to better understand why they occurred.

The effects of the scripts used in this study could be tested in real educational settings with students who engage in sustained inquiry-based innovations as has been reported elsewhere (e.g., Weinberger et al. 2009). Such classrooms build on a collaborative learning culture so the students know one another and evolve social norms about how to inquire and collaborate. Zhang et al. (2009) found that for learners who engage in longer collaboration and knowledge building, a less scripted and more opportunistic collaboration structure can be more productive. It would be insightful to investigate whether such CSCL scripts (as used in this study) would be beneficial in real classrooms for students who engage in sustained inquiry-based innovations. We suggest that follow up research be aimed at this question.

This study used a mixed quantitative and qualitative approach to analyze various dependent variables. We used an adapted coding scheme to analyze quality of student messages during the collaborative phase in terms of transactive knowledge sharing. The inter-rater reliability values of these instruments have been satisfactory in prior studies (e.g., Weinberger et al. 2005, 2007) and were even higher in the present study. We also used a content analysis approach to analyze domain-specific knowledge transfer measures as well as individual and group learning performance. Quantitative analyzes were used for assessing domain-specific knowledge transfer variables next to the qualitative approach for assessing the joint and individual problem solution plans. Although high inter-rater reliability and intra-coder test-retest reliability values for these measurements were obtained, we recommend also using course exams to measure learners' achievement in educational settings outside of the lab. Further analysis is needed to determine the extent to which the results of course exams (mid-term and final exams) are consistent with the results obtained in this study. If they are not consistent, and the psychometric properties of the exams pass the minimum quality thresholds, further calibration of the content analysis coding schemes (like the one we used) could be necessary.

The collaboration in this study was realized in the form of dyadic interactions. The scientific literature suggests that the nature of collaborative learning differs depending on group size, since active participation can be much higher and common ground can be established much faster and easier in dyads than in triads or larger groups (see Noroozi et al. 2012c). For example, communication and coordination difficulties increase with group size (Steiner 1972). This is especially important with respect to coordination of the learning task and knowledge specialization in the group, since it may take longer for learners to efficiently coordinate the distributed knowledge resources for improving performance in larger than in smaller groups. For example, Michinov and Michinov (2009) showed that dyads and triads differed in the way the coordination of specialized knowledge influenced enhancement of performance. It would be revealing to test the effects of transactive memory and discussion scripts on learning processes and outcomes using different-sized groups in order to better understand the relationship between group size and successful collaborative learning.

Contrary to most research studies on CSCL scripts, which mostly report on learning outcomes in relation to either individual or group performance (e.g., Weinberger and Fischer 2006; Weinberger et al. 2007), this study presents separate data on the quality of both joint and individual problem solution plans. This is important since success in a group's performance does not always mirror individual performance. Group members may employ strategies that enhance their group product, but this is not necessarily the same as individual performance (Prichard et al. 2006; Weinberger and Fischer 2006). For example, more active or knowledgeable members in the group may complete the task on behalf of the group; as a result, less active or knowledgeable members (so-called free riders) may fail to enhance their individual performance (Prichard et al. 2006). This is particularly interesting when the CSCL script targets the construction of a transactive memory system (TMS) in the group. As found in a study by Lewis et al. (2005), the TMS transfers across tasks; hence groups with a strong TMS develop it further on subsequent learning tasks. Such a transfer, however, happens only when group members maintain the same division of cognitive labour and roles across tasks (Lewis et al. 2005).

In the current study, although the division of labour and roles was absent in the subsequent individual learning task, comparable results were achieved for the effects of the CSCL scripts on both the quality of joint and individual problem solution plans. However, individual performance was measured immediately after the collaborative learning phase with a comparable problem case. This may have resulted in a misleading boost in the short-term individual performance measures that may not have been realized if the individual post-test had been conducted some time later with a rather different learning task (see Noroozi et al. 2012b). Domain-specific dependence, especially in a multidisciplinary collaborative setting, might take away the responsibility of individuals for learning new information that falls in another group member's area of specialization (see Lewis et al. 2005). This domain-specific dependence may thus hinder performance for comparable learning tasks that need complementary expertise and have to be subsequently solved individually without the presence of the domain expertise of the learning partner. It remains to be investigated to what extent the effects of CSCL scripts on joint product translate into the long-term impacts of such scripts on individual outcomes. Therefore we suggest that follow up research be aimed at this question. This could have consequences not only for the design principles of such scripts, but also for the transfer of learning from group to individuals in a long-term study.

We found interaction effects for the transactive memory and discussion scripts on various dependent variables in this study. We attributed these interaction effects to (the combination of) over-scripting, the short duration of the study and the multidisciplinary context. Scientific literature suggests that scripts could be faded out to avoid cognitive overload and frustration in overly scripted collaborative learning tasks (Dillenbourg 2002; Jermann and Dillenbourg 2003). The collaborative phase of the current study only lasted 80 min and within such a short period of time it was not possible to fade out the transactive memory and discussion scripts. Now that we know that both transactive memory and discussion scripts work well individually in a multidisciplinary problem-solving setting in a rather short time period, we advise that follow-up studies fade out such scripts to possibly rule out the interaction effects of such scripts over a relatively long period of time. Longer duration studies would allow researchers to fade out such CSCL scripts to avoid over-scripting. This is an important issue since overly rigid scripts would inhibit and spoil the richness of natural interaction, whereas overly flexible scripts would fail to elicit the intended interaction (Dillenbourg and Tchounikine 2007). Therefore we suggest that further research focus on how, when and under what conditions CSCL scripts need to be employed and then faded out to avoid over-scripting, prevent frustration, and foster learning in multidisciplinary groups.

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