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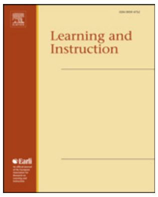

Scripting for construction of a transactive memory system in multidisciplinary CSCL environments

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ABSTRACT

Establishing a Transactive Memory System (TMS) is essential for groups of learners, when they are multidisciplinary and collaborate online. Environments for Computer-Supported Collaborative Learning (CSCL) could be designed to facilitate the TMS. This study investigates how various aspects of a TMS (i.e., specialization, coordination, and trust) can be facilitated using a transactive memory script that spans three interdependent processes (i.e., encoding, storage, and retrieval) in multidisciplinary CSCL. Sixty university students were assigned to multidisciplinary pairs based on their disciplines (water management or international development). These pairs were randomly assigned to a scripted or non-scripted condition and asked to discuss and solve a problem case. The script facilitated construction of a TMS, fostered learners' knowledge transfer and convergence, and improved the quality of problem solution plans. Specialization and coordination aspects of the TMS were mediators for the impacts of the script on joint but not individual problem solution plans.

1. Introduction

For solving complex problems, professionals often need to collaborate in multidisciplinary teams. The main advantage of such teams is that their members benefit from one another's complimentary expertise and bring various perspectives to bear on a problem to create new ideas. Such a knowledge integration in two or more disciplines may raise new questions in such a way that would have been impossible through single-disciplinary thinking (e.g., Boix-Mansilla, 2005). However, newly-formed multidisciplinary group members have little meta-knowledge about one another's knowledge, hence, they may encounter difficulties during collaboration, such as coordinating joint problem-solving activities (Barron, 2000), establishing common ground (Beers, Boshuizen, Kirschner, & Gijselaers, 2005), pooling and processing unshared information (Rummel, Spada, & Hauser, 2009), and converging towards shared knowledge (Roschelle & Teasley, 1995). This lack of knowledge can negatively affect the exchange of unshared information especially in newly-formed groups (Schreiber & Engelmann, 2010). Encoding, storing, and retrieving knowledge in the group whilst building on and expanding knowledge about learning partners' expertise is named Transactive Memory System (TMS) (Wegner, 1987, 1995).

Recently, some studies (e.g., Schreiber & Engelmann, 2010) have shown that Computer-Supported Collaborative Learning (CSCL) can be designed to overcome barriers for establishing a TMS. Using concept maps to visualize collaborators' knowledge structures can initiate construction of a TMS, which in turn benefits group performance (Schreiber & Engelmann, 2010). In this paper, we present another innovative approach to facilitate construction of a TMS using a transactive memory script. Scripts have shown to be a promising approach to orchestrate various roles and activities of learners, to facilitate interaction and task coordination, and ultimately to foster learning (see Fischer, Kollar, Mandl, & Haake, 2007; Noroozi, Weinberger, Biemans, Mulder, & Chizari, 2012; Weinberger, 2011). This study examined the extent to which a TMS could be facilitated by a transactive memory script in a multidisciplinary setting. In addition, the extent to which this specific script influenced learners' knowledge transfer as well as joint and individual problem solution plans was studied.

1.1. Transactive memory system

The TMS theory (Wegner, 1987) originally described how families coordinate their memory and tasks at home. It refers to the interactions between individuals' internal and external memory

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systems while communicating (Wegner, 1987, 1995). Meanwhile, TMS has also been studied in educational settings (e.g., Engelmann & Hesse, 2010). In collaborative learning, not only one's own knowledge as an internal source comes to play but also the learning partners' knowledge as external sources. In a 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. A TMS thus combines the knowledge stored in each individual's memory with knowledge structures of the learning partners for developing a shared awareness of who knows what in the group (Moreland, Argote, & Krishnan, 1996, 1998). A TMS refers to group members' knowledge awareness, the accessibility of that knowledge, and the extent to which members take responsibility for providing knowledge in their own area of expertise and for retrieval of information held by others in the group (Lewis, 2003; London, Polzer, & Omoregie, 2005). These processes could result in forming a collaboratively shared system of encoding, storing, and retrieving information for enhancing group performance (Wegner, 1995).

1.2. *Various processes of a TMS: encoding, storage, and retrieving*

Establishing a TMS in a group involves three interdependent processes: encoding, storage, and retrieval (Wegner, 1987, 1995). In collaborative settings, 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 needed information from each individual when performing the task some time later (Rulke & Rau, 2000; Wegner, 1987, 1995). In the encoding process, directory updating begins with the process of getting to know "who knows what" in the group (see Schreiber & Engelmann, 2010). During this process, group members gain an estimation of their partners' areas of expertise, and categorize this information by ascribing each knowledge domain to the corresponding persons (Liang & Rau, 2000). In the storage process, group members store information with the individuals who have the specific expertise on a particular topic. During this process, group members allocate new information on a topic to the relevant experts on that topic. In the retrieving process, group members retrieve required information from the experts who have the stored information on a particular topic (Wegner, 1987, 1995).

1.3. *Various aspects of a TMS: specialization, coordination, and trust*

Establishing and maintaining a TMS has mainly been studied along with three main aspects of a TMS in a group, namely specialization, coordination, and trust (see Lewis, 2003). Specialization represents the awareness and recognition of expertise distributed in the group. Trust or credibility represents the extent to which group members trust and rely on each other's specific expertise. Coordination represents the group members' ability to work together efficiently on a learning task with a low degree of confusion and misunderstandings (Michinov & Michinov, 2009).

For this study, it is important to describe the relation between various processes and aspects of a TMS in collaborative learning settings. In the following section, essential interdependent processes for establishing a TMS (encoding, storage, retrieval) are explained in relation to the main aspects of a TMS (specialization, coordination, trust).

1.4. *Relations between various processes and aspects of a TMS*

Specialization is the product of the encoding process, which reflects the differentiation of one's own expertise from the knowledge repertoire of other group members (Wegner, 1995). This explication of expertise (encoding) allows the group to acquire complementary knowledge and enlarge its collective knowledge (Michinov & Michinov, 2009). Specialization occurs when group members encode one another's expertise and label information as belonging to members whom the group trusts most as the source of expertise (Lewis, 2003). Encoding could be best achieved through proper interaction between group members as a first essential step towards specialization (Wegner, 1987, 1995). This explication of expertise helps learners initiate a productive discussion to pool and process unshared knowledge resources rather than engaging in discussions of information already shared among them (e.g., Rummel et al., 2009; Stasser Stewart, & Wittenbaum, 1995) or discussions to establish common ground (Beers et al., 2005). Speeding up the process of pooling unshared information as a way to heighten awareness of distributed knowledge resources in a group can be seen in the form of knowledge elicitation or externalization for the learning partners according to their areas of specialization. These transactions may further be followed by the exchange of specialized feedback in the form of enquiry, clarification, or elaboration of the learning materials (e.g., Rummel & Spada, 2005).

Specialization plays an important role during the storage process. Based on the estimation of knowledge awareness and recognition of expertise distributed in the group, learners can coordinate the distributed knowledge, assign responsibility to the expert in the group, and store relevant information that fits their domains of expertise (Wegner, 1987, 1995). Coordination also plays a key role during the storage process since group members need to assign responsibility to the individual who has the most expertise on a particular topic (Lewis, 2003; Rulke & Rau, 2000). Coordination in a group is best achieved in the storage process when learners share the task and collaboratively assign responsibilities based on the labelled information in the encoding process (Lewis, 2003). Trust is also important during the storage process since learning partners should make sure that the knowledge that is required for solving the task is stored by one of the credible group members.

Coordination comes to play during the retrieval process since group members need to turn to the relevant experts for the retrieval of information based on the members' expertise (Wegner, 1995). Retrieval coordination is best achieved when group members provide relevant information on the topic and analyse parts of the task based on assigned tasks and roles in relation to their specialized expertise. Finally, they can combine their analyses followed by discussions and elaborations on the basis of their own and the learning partner's specialized expertise (Lewis, 2003; Rulke & Rau, 2000). Trust also plays an important role during the retrieval process since learners need to make sure that the partners' stored information is credible when combining and retrieving knowledge and information for accomplishing the joint learning task. In problem-solving settings, learners may use their meta-knowledge for coordinating subtasks and the division of labour such that their individual contributions can later be assembled into a group product (Dillenbourg, 1999). In such an approach, 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. Learners may also use their meta-knowledge for elaborating on the material, integrating and synthesizing one another's perspectives and ideas in order to jointly make sense of the learning task (e.g., Schoor & Bannert, 2011; Weinberger & Fischer, 2006). This productive interaction followed by persuasive discussions would help learners revise, modify, and adjust their initial contributions on the basis of their partners' contributions. In this form of combining knowledge, partners use their meta-knowledge not only for coordinating subtasks, but also for creating novel information by integrating their individual expertise. This integrative form of combining knowledge may create a TMS in the group since information coming from different locations in the system is tied together by a common label leading to elaboration of the material and knowledge of the partners for discovering new knowledge for the group (Dillenbourg, 1999).

The third aspect of TMS, trust, is the result of the other two aspects, namely specialization and coordination (Lewis, 2003). The level of trust in a group can be enhanced if learners make sure that their learning partners' knowledge is credible (Lewis, 2003). When members of a learning group are not fully aware of other members' expertise, they may exhibit a lack of trust, for example by ignoring or disregarding information submitted by their learning partners (Zheng, 2012). Making portfolios of one's own and the learning partners' expertise in the encoding process, coupled with interaction between group members, sharing one's own knowledge and externalizing others' knowledge during the storage and retrieval processes allows group members to judge and evaluate the trustworthiness, accuracy, and credibility of their learning partners' knowledge (Moreland et al., 1996, 1998; Rulke & Rau, 2000). Mutual trust could be achieved by appropriate communication between group members for sharing task responsibilities based on each member's relevant experience. However, over-reliance on trust without the effective utilization of members' expertise has been argued to be counterproductive (Zheng, 2012). This often happens when learners exhibit a high level of mutual trust without accurately understanding individual members' expertise. When learning partners build mutual trust based on the awareness of each other's expertise, they are willing to not only externalize their specialized knowledge but also confront each other without worrying about negative consequences (Zheng, 2012). Building such trust can help learning partners elaborate on the learning materials and challenge one another's opinions in a psychologically safe environment (Edmondson, 1999).

1.5. *Computer-supported collaboration scripts to facilitate a TMS*

Different approaches have been used to facilitate construction of a TMS in both organizational and educational settings, including individual and group training (e.g., Liang, Moreland, & Argote, 1995), formation of groups based on complementary expertise (e.g., Hollingshead, 2000), and computer-supported settings (e.g., Schreiber & Engelmann, 2010). This paper focuses on the use of computer support systems to facilitate construction of a TMS in a multidisciplinary setting. These platforms, known as Computer-Supported Collaborative Learning (CSCL), allow for the embedding of various representational structures to facilitate knowledge sharing. These structures can be represented graphically (e.g., digital maps or awareness tools) (e.g., Noroozi, Biemans, et al., 2012; Noroozi, Busstra, et al., 2012) or textually (e.g., scripts) to guide learners' interactions and to co-construct shared knowledge (e.g., Weinberger, Ertl, Fischer, & Mandl, 2005). In CSCL, partners are seen as additional learning resources when they contribute unshared prior knowledge to the discussion, which may eventually be shared after collaboration (Weinberger, Stegmann, & Fischer, 2010). Interacting with one another in CSCL and being involved in various social, epistemic, and argumentative activities, learners could (co)construct knowledge that can also be applied to solve complex and ill-defined problems (e.g., Janssen, Erkens, Kirschner, & Kanselaar, 2010).

One of the most prominent instructional approaches in CSCL is the use of computer-supported collaboration scripts that can facilitate both knowledge construction and transfer as well as problem-solving activities. Such scripts can be textually implemented into the CSCL platform in a variety of forms such as cues, prompts, or input text boxes (e.g., Weinberger et al., 2005) to foster both collaborative (e.g., Fischer, Bruhn, Gräsel, & Mandl, 2002) and individual learning (e.g., Weinberger et al., 2005). Scripts are specific instructions that stipulate the type and sequence of collaborative learning activities in order to help group members accomplish tasks (see Dillenbourg & Tchounikine, 2007; Noroozi, Biemans, et al., 2012; Noroozi, Weinberger, et al., 2012). Epistemic scripts structure and sequence discourse activities with respect to the content and task strategies (Weinberger et al., 2005). Such a script can be used to facilitate the specialization aspect of the TMS by providing guidelines for learners to appropriately engage in task-oriented activities on the basis of their specialized expertise (e.g., Schellens, Van Keer, De Wever, & Valcke, 2007). A social script specifies and sequences learners' discourse activities with respect to the transactive social modes and interaction strategies (Weinberger et al., 2005). Such a script can be used to facilitate the specialization aspect of the TMS by providing guidelines for learners to adopt adequate interaction and social strategies such as eliciting, externalization and transactivity (responding critically to partners' contributions). Collaboration scripts provide explicit guidelines for small groups of learners to clarify when and by whom certain activities need to be executed (see Fischer et al., 2007). Such a script can be used to facilitate the coordination aspect of a TMS by assigning responsibilities for the division of labour and roles as well as time management (see Strijbos, Martens, Jochems, & Broers, 2004, 2007). Students with collaboration scripts engage in more transactive discussions and thus benefit more from the external memories available, for example, contributions of their learning partners (Teasley, 1997). CSCL scripts could be designed to regulate learners' interaction and coordination strategies (e.g., Fischer & Mandl, 2005), also for multidisciplinary groups of learners (see Rummel & Spada, 2005). The role of these scripts, however, has not been reported as such in relation to the interdependent processes of the TMS in multidisciplinary CSCL settings.

1.6. *Hypotheses*

We test the following hypotheses:

Hypothesis 1. A transactive memory script facilitates various aspects of a TMS in multidisciplinary CSCL settings.

Since all essential processes for establishing a TMS in a group (encoding, storage, retrieval) were targeted by specific prompts, it was hypothesized that the transactive memory script would be effective in facilitating various aspects of a TMS (specialization, coordination, trust) without long-lasting interaction in ad hoc groups of experts to solve a complex problem.

Hypothesis 2. A transactive memory script fosters learners' knowledge transfer and convergence (hypothesis 2a) and also improves quality of joint and individual problem solution plans (hypothesis 2b) in multidisciplinary CSCL settings.

Since specific prompts were designed to facilitate coordination of the distributed knowledge in the group, it was hypothesized that learners' knowledge transfer and convergence would be facilitated (hypothesis 2a). Building on the positive impact of a TMS on group performance, it was hypothesized that the transactive memory script would improve the quality of joint problem solution plans. Furthermore, since a comparable case-based assignment was used to assess the quality of individual problem solution plans right after the collaborative learning phase, it was hypothesized that the transactive memory script would also improve the quality of individual problem solution plans as well as knowledge transfer (hypothesis 2b).

Hypothesis 3. A TMS mediates the impacts of the transactive memory script on the quality of learners' joint and individual problem solution plans in multidisciplinary CSCL settings.

If the first and second hypotheses of this study are confirmed, we can also expect that the specific aspects of a TMS could explain the underlying impacts of a transactive memory script on the quality of joint and individual problem solution plans.

2. Method

2.1. Participants

The study took place at Wageningen University in the Netherlands. The participants were 60 MSc students from two disciplinary backgrounds, that is, international land and water management as well as international development studies. Their mean age was 24.93 ($SD = 3.40$) years, and the majority (63%) was female. The numbers of Dutch and foreign students were about equal.

The participants, who were compensated €50 for their contribution, were divided into multidisciplinary pairs based on their disciplinary backgrounds. Participants were randomly paired, with one learner having a water management disciplinary background and the other an international development background. The participants in each pair did not know each other beforehand. Next, each pair was randomly assigned to either the treatment condition (scripted) or the control group (unscripted), each of which included 15 pairs. The experimental condition differed from the control condition only with respect to the presence of the transactive memory script that was implemented in the platform.

2.2. Learning materials

The subject to be learnt was the concept of Community-Based Social Marketing and its application in Sustainable Agricultural Water Management. The participants' task was to apply these concepts in fostering sustainable behaviour among farmers (see Noroozi, Weinberger, Biemans, Mulder, & Chizari., 2013). 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 the theoretical concepts, and the demographic characteristics of the farmers and geographical characteristics of the location.

2.3. Implementation of the transactive memory script in the CSCL platform

An asynchronous text-based discussion board called SharePoint was customized for the collaboration phase (see Noroozi et al., 2013 for further information on the CSCL platform). The goals of collaboration were for the students to share as much knowledge as possible and to discuss and elaborate on the theoretical concepts in each partner's specific domain to collectively design sound solution plans for the problem case.

In the control condition, the learning partners received no further support beyond being asked to analyse, discuss, and solve the problem case based on the conceptual space and to type their arguments into a blank text box.

In the experimental condition, the platform included a script with three phases: building awareness, storage, and retrieval. For each phase, specific types of prompts were embedded in the CSCL platform. However, all learners' replies were standard messages without a prompt. The number of prompts was different for each phase. Each learner received three prompts for the building awareness phase, two for the storage phase, two for the individual retrieval phase, and two for the collaborative retrieval phase. Respective sets of prompts were given to learners at four intervals (building awareness, storage, individual and collaborative retrieval phases). For all four intervals, learning partners were able to see one another's prompts and their respective responses after they were submitted into the CSCL platform. The CSCL platform offered the particular set of prompts and learners were responsible for selecting these prompts and then replying to them accordingly. These prompts are described below.

In the building awareness 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, and 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..."). These prompts were intended to facilitate the encoding process and specialization aspect of the TMS by creating knowledge awareness and recognition of expertise distributed in the dyad. These prompts, in line with epistemic and social scripts, help learning partners engage in discourse activities for knowledge elicitation and externalization on the basis of their awareness of one another's specialized knowledge (see Noroozi, Biemans, et al., 2012; Noroozi, Weinberger, et al., 2012; Schellens et al., 2007; Weinberger et al., 2005).

In the storage phase, the group members were given 15 min to read the portfolios and discuss the case, with the goal of distributing responsibility for the learning task. Respective prompts aimed at helping 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 was pre-structured with prompts, such as: "The following aspects of the task should be analysed by..."; "I will take responsibility for the following aspects of the learning task...". The group members were asked to compose at least one task distribution and one acceptance of responsibility message. These prompts were intended to facilitate the coordination aspect of a TMS through the assignment of responsibilities for labelling information and acceptance of those responsibilities, based on the partners' complementary expertise. These prompts, in line with collaboration scripts, help learners clarify what, when and by whom certain activities need to be executed to accomplish the task (e.g., Weinberger et al., 2005).

In the individual part of the retrieval phase, the group members were given 15 min to analyse and solve previously assigned parts of the task based on their specific expertise. The content of the initial messages was pre-structured with prompts (e.g., "The task aspects related to expertise XY are addressed as follows…"). In the collaborative part of the retrieval phase, learners were given 40 min and guided to combine their solutions on the basis of their specialized 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 based on argumentation. The content of 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...". These prompts were intended to facilitate the coordination aspect of a TMS by guiding learners to coordinate the processes of retrieving and including knowledge of both partners. These prompts, in line with collaboration scripts, stipulate the type and sequence of learning activities to help group members collaborate and accomplish tasks (Weinberger et al., 2005).

As discussed above, the trust aspect of a TMS as the outcome of the other two aspects was expected to be indirectly facilitated through the transactive memory script for all processes of a TMS (Lewis, 2003).

2.4. Procedure

In a pilot study with eight learners we first ensured adequate levels of task difficulty, comprehensibility of the learning material, applicability of the tests and the technical functioning of the script and the learning environment.

Overall, the experimental session took about 3.5 h and consisted of four phases with a 10-min break in-between. (1) During the introduction and pretest phase, which took 35 min, learners received introductory explanations for 5 min. They were then asked to complete several questionnaires (30 min) on demographic characteristics an additional control variables such as computer literacy and prior experience with and attitude towards collaboration. The data from these tests were used to check for randomization (see section Control Measures). (2) During the individual learning phase, learners first received an introductory explanation of how to analyse 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 and also demographic characteristics of the farmers and the location of the case study. Learners were allowed to make notes and keep the text and their notes during the experiment. Prior to collaboration, learners were asked to individually analyse the problem case and design an effective plan (20 min) for fostering sustainable behaviour on the basis of their own domain of expertise. The data from this test served two purposes: to assess learners' prior knowledge regarding their own domains of expertise, and to help us check for the randomization of learners in terms of prior knowledge over two conditions. After a 10-min break, (3) the 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 argue their analyses and design plans in pairs (80 min). Specifically, they were asked to jointly design an effective plan for fostering sustainable behaviour among Nahavand wheat farmers. This joint solution served as the criteria for assessing the quality of joint problem solution plans. (4) During the posttest 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 learnt in the collaboration phase. Specifically, they were asked to analyse and design an effective plan for fostering sustainable behaviour among Nahavand wheat farmers in terms of irrigation methods as an advisor. This individual task was used for assessing the quality of individual problem solution plans. Furthermore, as a posttest, learners were asked to fill out several questionnaires to assess various aspects of a TMS and their satisfaction with the learning experience (20 min). Finally, the participants got a short debriefing for about 5 min.

2.5. Measurements, instruments, and data sources

2.5.1. Measurement of the TMS

Studies conducted to date on TMS differ in terms of measurement approaches. Most authors favour a multi-method approach (see Moreland, Swanenburg, Flagg, & Fetterman, 2010). We employed two different approaches to measure the TMS.

2.5.1.1. Measurement of the TMS by questionnaire. We adapted a questionnaire from Lewis (2003) to assess the learners' TMS (see Table 1). This questionnaire consisted of three sections corresponding to three aspects of the TMS, namely specialization (e.g., "My partner's specialized knowledge was needed to complete the task"), coordination (e.g., "Our team had very few misunderstandings about what to do"), and trust (e.g., "I trusted that my partner's further knowledge about the case was credible") with 15 items in total on a five-point Likert scale ranging from "strongly disagree" to "strongly agree". In this study, the reliability coefficient was satisfactory for all three aspects of the TMS (Cronbach α: .75, .78, and .74, respectively).

Table 1
The transactive memory system scale items.

Specialization	Each team member has specialized knowledge of some aspect of the case.
	I have different knowledge about an aspect of the case than my partner has.
	Different team members were responsible for expertise in different areas.
	My partner's specialized knowledge was needed to complete the task.
	I now know what expertise my partner has and the specific areas it relates to.
Trust	I was comfortable accepting procedural suggestions from my partner.
	I trusted that my partner's further knowledge about the case was credible.
	I was confident relying on the information that my partner brought to the discussion.
	When my partner contributed information, I wanted to double-check it for myself (reversed).
	I did not have much faith in my partner's "expertise" (reversed).
Coordination	Our team worked together in a well-coordinated fashion.
	Our team had very few misunderstandings about what to do.
	Our team needed to backtrack and start over a lot (reversed).
	We accomplished the task smoothly and efficiently.
	There was much confusion about how we would accomplish the task (reversed).

2.5.1.2. Measurement of the TMS using discourse. We adapted a coding scheme developed by Rummel and Spada (2005) and Rummel et al. (2009) and used the interaction patterns of the dyads of learners during discourse to measure TMS. Specialization was operationalized in terms of the number of messages that were allocated for (1) elicitation, (2) externalization, and (3) giving feedback. When learners asked for or invited a reaction from their partners, we coded the message as elicitation (e.g., "What are the possible technical problems in the area in terms of implementing a sprinkler irrigation method?"). Typically, this was done by asking questions, however, learners often forgot the question marks or made proposals rather than asking directly (e.g., "We should also talk about the external barriers for behaviour change."). When learners outlined their knowledge and explained new content to their partners 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 (e.g., "I would encourage farmers to use a drip irrigation method since there is steeply sloped land in the area and this could prevent runoff."). Learners might have juxtaposed externalizations, that is, a reply to earlier externalizations, with an externalization. When learners outlined their knowledge and gave feedback to the learning partner in response to earlier messages and the questions raised, for instance, when they provided clarifications and elaborations for their already externalized information during discussion, we coded the message as giving feedback. We then computed all messages that were allocated for elicitation, externalization, and giving feedback and used the total as an indicator for the specialization aspect of the TMS.

Coordination was operationalized in terms of the number of messages that were allocated for (1) time management, (2) task division (in terms of labour and roles), and (3) technical coordination. When learners checked for the timeline, arranged a timetable or referred to the time (e.g., “Time is running out quickly.”; “How much time is left?”; “Write down your answer faster.”; “Only 20 min left to come up with our joint solution.”), we coded the message as time management. When learners referred to assigning or acceptance of task responsibility regarding who should do what, we coded the message as task division (e.g., “Shall I write about the type of irrigation and you write about the external barriers in technology adoption?”; “Can you take responsibility for the social aspects of the learning task?”). When learners asked or explained anything regarding the functionality of the platform (e.g., “Are we supposed to put our individual analysis in the text editor?”), we coded the message as technical coordination. We then computed all messages that were allocated for time management, task division, and technical coordination and used the total as an indicator for the coordination aspect of the TMS.

There were other types of messages during the collaborative phase (e.g., task enjoyment, task motivation, off-task messages) that could not be allocated to specialization or coordination indicators in this experiment (e.g., “I really enjoy using the platform, do you?”; “It was a great idea to participate in this experiment.”). As these types of messages were not indicators of the TMS and as they were not targeted by the script, we excluded them from further analysis.

Trust was operationalized in terms of the extent to which the learners in the dyad trusted the knowledge of their partners. Trust could be established between learners when they agreed to incorporate theoretical concepts that were discussed during discourse into their joint problem solution plan. As a data source, the contributions of the two learners in a dyad to the discourse corpora and to the joint problem solution plan were used. As an indication of the level of trust of learner A in learner B, the number of theoretical concepts (present in the joint solution plan) originally introduced by learner B was divided by the total number of concepts brought in by learner B in the discourse. The same procedure was done to assess the level of trust of learner B in learner A. To calculate a total trust score for each dyad, the individual trust scores for learners A and B were added and divided by 2.

Two trained coders coded three discourse corpora in each condition. Both inter-rater agreement (Cohen’s $\kappa = .88$) and intra-coder test–retest reliability for each coder for 10% of the data (93% of identical scores) was sufficiently high. The scores for each aspect of the TMS were transformed into proportions. A pair’s score on specialization and coordination aspects of the TMS was divided by the total number of messages that they produced during discourse. In such an approach, we could measure to what extent each pair of learners allocated their discourse activities to each specific aspect of the TMS.

2.5.2. Measuring knowledge transfer

Knowledge transfer measures were analysed based on an expert solution. This expert solution included all the possible theoretical concepts and their relations to one another and to the problem cases, as in Noroozi et al. (2013). The next step involved characterizing the content of all individual representations, both before (pretest) and after collaboration (posttest), and the group representation. Learners received numerical credits for adequately applying theoretical concepts and for relating them appropriately to one another and to case information in their solution plans. Both inter-rater agreement between two coders (Cohen’s $\kappa = .88$) and intra-coder test–retest reliability for each coder for 10% of the data (90% of identical scores) were sufficiently high. The descriptions of various forms of knowledge transfer are as follows.

2.5.2.1. Individual-to-group knowledge transfer. The impact that each individual learner may have on the group solution plan was estimated by the total number of his/her own individual representations incorporated in the group 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 his/her theoretical concepts that were incorporated in the dyad’s joint solution plan.

2.5.2.2. Group-to-individual knowledge transfer. The impact that each dyad may have on the individual learner was estimated by the total number of relevant and correct applications of a learning partner’s theoretical concepts that were transferred from the shared group cognition (present in joint solution plan) to the individual cognitions (individual posttest measures). The indicator of group-to-individual knowledge transfer for each participant was then the sum score of all relevant and correct applications of the learning partner’s theoretical concepts from the joint solution plan that were transferred to an individual’s solution plan in the posttest.

2.5.2.3. Knowledge convergence. We used individual learners’ solution plans after the collaborative learning phase to measure knowledge convergence between individual members of the dyads. Knowledge convergence refers to knowledge that learning partners share after collaborative learning (i.e., Jeong & Chi, 2007; Weinberger, Stegmann, & Fischer, 2007). The indicator of knowledge convergence for each dyad was the sum score of all relevant and correct applications of theoretical concepts, which both partners appropriately shared in their individual representations in the posttest case analysis (see also Fischer & Mandl, 2005).

2.5.3. Measuring quality of collaborative and individual problem solution plans

The measure of group performance was operationalized as the quality of the joint solution plan produced by the dyad during discourse. The measure of individual performance was operationalized as the quality of the individual solution plan produced by each learner after collaboration in the posttest written analysis.

The strategy adopted for measuring the quality of collaborative 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 solution plan. Both group and individual solution plans were independently rated by two coders on a four-point scale ranging from “inadequate solution plan” (0 points) to “high-quality solution plan” (4 points) (see Table 2). Both inter-rater agreement between two coders (Cohen’s $\kappa = .91$) and intra-coder test–retest reliability for each coder for 10% of the data (95% of identical scores) were sufficiently high. We calculated the mean quality score for the joint (group values) and individual (aggregated individual values) problem solution plans in both conditions.

2.6. Control measures

Learners’ prerequisites, such as computer literacy and prior experience with and attitude towards collaboration, are seen as relevant and important in CSCL settings (see Noroozi, Biemans, Busstra, Mulder, & Chizari, 2011). We therefore controlled for uneven distribution of these measures over the two conditions (see Noroozi et al., 2013; for further description of these measurements).

2.7. Unit of analysis and statistical tests

We used the individual learner as the unit of analysis to measure the control variables in the individual pretest. We used the dyads as

Table 2
Coding rubric for quality of collaborative and individual problem solution plans.

Code	Description
Inadequate solution plan quality	Solution plan is weakly supported, if at all. The solution plan only contains everyday concepts and case information. None or hardly any aspect of the theoretical concepts is discovered.
Low quality solution plan	The solution plan is partly supported by a mix of theoretical concepts in relation to the problem case with little, if any, discussion and justification of the assumptions made.
Rather low quality solution plan	The solution plan is adequately supported by a mix of theoretical concepts in relation to the problem case. Assumptions made are not, however, adequately elaborated on, justified, or discussed.
Rather high quality solution plan	The solution plan is adequately supported by a mix of theoretical concepts in relation to the problem case. Assumptions made are partly elaborated on, discussed, or justified.
High quality solution plan	The solution plan is adequately supported by a mix of theoretical concepts in relation to the problem case. Assumptions made are adequately elaborated on, discussed, or justified. Almost all or all of the relation between theoretical concepts and problem case are discovered, discussed, and justified.

the unit of analysis (group values) only to measure the quality of joint problem solution plans and knowledge convergence, which were based on the collaborative solution of the learning task. Although the rest of the dependent variables were measured at the individual level, these measurements were not independent observations due to the collaboration that preceded it (Kapur, 2008; Kirschner, Paas, Kirschner, & Janssen, 2011). Therefore, we used aggregated individual values to analyse various aspects of the TMS, individual-to-group and group-to-individual knowledge transfer measures as well as individual problem solution plans. For all the analyses, the coders were unaware of participant characteristics. Due to the presence of the prompts of the script, the coders were aware of the treatment condition of the online discussion. Therefore, the coding was not blind to the condition with respect to the collaborative discourse analyses. However, due to the lack of prompts of the script in the joint and individual problem solution plans, all the analyses for the rating of quality of these measures were blind to the condition.

The scores of two inactive pairs of learners (one pair in each condition) were excluded from the analyses due to the incompleteness of their contributions. For personal reasons, one learner in each of two pairs decided not to continue with the experiment after the 10-min break. Therefore, for data analyses, 56 learners (14 pairs in each of the two conditions) were included in the study.

A one-way multivariate analysis of variance (MANOVA) was conducted to determine the effects of a transactive memory script on construction of various aspects of a TMS (i.e., specialization, coordination, trust), knowledge transfer measures (individual-to-group, group-to-individual knowledge transfer, and knowledge convergence), and quality of problem solution plans (joint and individual). ANOVAs for each of these dependent variables were then conducted as follow-up tests to the corresponding MANOVA. A Pearson correlation coefficient was computed to assess the relationship between different components of TMS as assessed by questionnaire and interaction data analysis.

Following Barron and Kenny (1986), regression analyses for casual steps were used to determine whether the TMS mediates the impacts of transactive memory script on quality of joint and individual problem solution plans. We further evaluated the mediation effect of the TMS by the Sobel test, which is a significance test of indirect mediation impact (Sobel, 1982). Specifically, we used this approach for calculating indirect effect tests using the standard error for the product of regression coefficients. Regression analyses were performed separately for joint and individual problem solution plans. The coefficient of transactive memory script was the experimental variation between the control and the experimental condition.

3. Results

3.1. Learning prerequisites and control measures

The learners with an international development studies background in the two conditions showed no differences with respect to prior knowledge, $F(1, 26) = .22$, $p = .64$ and number of passed courses on community-based social marketing and related topics, $F(1, 26) = .46$, $p = .50$. The same was true for the learners with an international land and water management studies background regarding prior knowledge, $F(1, 26) = .16$, $p = .69$ and number of passed courses on sustainable agricultural water management and related topics, $F(1, 26) = .09$, $p = .76$. Furthermore, learners in the two conditions showed no differences regarding the mean scores of computer literacy, $F(1, 54) = .27$, $p = .54$, and prior experience with collaboration, $F(1, 54) = .16$, $p = .67$. The same was true for the learners' attitudes towards collaboration, $F(1, 54) = .24$, $p = .57$. These results showed that there were no substantial differences between learners' individual prerequisites in the two conditions.

3.2. The effects of a transactive memory script on construction of a TMS (hypothesis 1)

Based on measurement of TMS by questionnaire, the average score for a TMS as a whole was higher for scripted than unscripted learners, *Wilks'* $\lambda = .37$, $F(1, 26) = 13.41$, $p < .01$, $\eta^2 = .63$. Specifically, the difference between specialization means was significant, $F(1, 26) = 29.11$, $p < .01$, $\eta^2 = .53$, with scripted learners ($M = 4.63$, $SD = .27$) scoring higher than unscripted learners ($M = 3.81$, $SD = .50$). Similarly, the difference in trust means was significant, $F(1, 26) = 18.80$, $p < .01$, $\eta^2 = .42$, with scripted learners ($M = 4.64$, $SD = .40$) scoring higher than unscripted learners ($M = 3.95$, $SD = .44$). Coordination means also differed significantly, $F(1, 26) = 9.24$, $p < .01$, $\eta^2 = .26$, with scripted learners ($M = 4.35$, $SD = .47$) scoring higher than unscripted learners ($M = 3.75$, $SD = .57$).

Based on measurement of the TMS during discourse, the average score for the TMS as a whole was higher for scripted than unscripted learners, *Wilks'* $\lambda = .11$, $F(1, 26) = 67.03$, $p < .01$, $\eta^2 = .89$. Specifically, the mean scores for specialization, $F(1, 26) = 176.93$, $p < .01$, $\eta^2 = .87$, and coordination, $F(1, 26) = 131.38$, $p < .01$, $\eta^2 = .83$, were different between scripted and unscripted learners. In the scripted condition ($M = .89$, $SD = .07$), about 37% more specialization messages were exchanged in comparison to the unscripted condition ($M = .49$, $SD = .09$). Instead, in the unscripted condition ($M = .38$, $SD = .09$), about 31% more coordination messages were exchanged in comparison to the scripted condition ($M = .07$, $SD = .05$). Trust means did not differ significantly, $F(1, 26) = .45$, $p = .51$, with scripted learners ($M = .66$, $SD = .05$) scoring about the same as unscripted learners ($M = .64$, $SD = .07$).

We found a positive correlation between the specialization aspect of the TMS in the two measures, $r = .67(28)$, $p < .01$. There was a negative correlation between the coordination aspect of the TMS in the two measures, $r = -.47(28)$, $p < .05$, meaning that learning dyads that allocated more messages for coordination activities during the collaborative phase scored lower with respect to satisfaction with their coordination in the questionnaire and vice versa. There was no significant correlation between the mutual trust aspect of the TMS in the two measures, $r = -.01(28)$, $p = .95$.

Concerning the inter-correlation between various aspects of the TMS based on discourse data, we found a negative correlation between specialization and coordination, $r = -.92(28)$, $p < .01$, meaning that learning dyads that allocated more messages for coordination activities scored lower for specialization during discourse and vice versa. The trust was correlated with neither specialization, $r = .19\ (28)$, $p = .32$, nor coordination, $r = -.017(28)$, $p = .93$, aspects of the TMS. Concerning the inter-correlation between various aspects of the TMS based on questionnaire data, we found positive correlations between all aspects of the TMS namely between specialization and coordination, $r = .54(28)$, $p < .01$, specialization and trust, $r = .53(28)$, $p < .01$, as well as coordination and trust, $r = .74(28)$, $p < .01$.

Overall, transactive memory script was effective in facilitation of the coordination and specialization aspects of the TMS. However, the script support was not effective in facilitation of the trust aspect of the TMS in newly-formed multidisciplinary learning dyads (hypothesis 1).

3.3. The effects of a transactive memory script on learners' knowledge transfer measures (hypothesis 2a) and quality of joint and individual problem solution plans (hypothesis 2b)

The average score for knowledge transfer measures as a whole was higher for scripted than unscripted learners, *Wilks'* $\lambda = .56$, $F(1, 26) = 6.24$, $p < .01$, $\eta^2 = .44$. Specifically, the difference between individual-to-group knowledge transfer means was not significant, $F(1, 26) = 1.08$, $p = .31$, with scripted learners ($M = 16.64$, $SD = 3.77$) scoring about the same as unscripted learners ($M = 15.14$, $SD = 3.86$). In contrast, the difference in group-to-individual knowledge transfer means was significant, $F(1, 26) = 16.95$, $p < .01$, $\eta^2 = .40$, with scripted learners ($M = 6.14$, $SD = 1.70$) scoring higher than unscripted learners ($M = 3.93$, $SD = 1.07$). Knowledge convergence means also differed significantly, $F(1, 26) = 19.01$, $p < .01$, $\eta^2 = .42$, with scripted learners ($M = 11.79$, $SD = 3.12$) scoring higher than unscripted learners ($M = 7.50$, $SD = 1.95$).

Overall, transactive memory script fostered group-to-individual knowledge transfer as well as knowledge convergence. However, the script support was not effective in fostering individual-to-group knowledge transfer in newly-formed multidisciplinary learning dyads (hypothesis 2a).

The average scores for quality of problem solution plans as a whole was higher for scripted than unscripted learners, *Wilks'* $\lambda = .72$, $F(1, 26) = 6.24$, $p < 4.81$, $\eta^2 = .28$. Specifically, the difference between joint problem solution plan mean scores was significant, $F(1, 26) = 9.09$, $p < .01$, $\eta^2 = .26$, with scripted learners ($M = 2.99$, $SD = .78$) scoring higher than unscripted learners ($M = 2.21$, $SD = .58$). Similarly, the difference in individual problem solution plan mean scores was significant, $F(1, 26) = 4.62$, $p < .05$, $\eta^2 = .15$, with scripted learners ($M = 2.93$, $SD = .76$) scoring higher than unscripted learners ($M = 2.43$, $SD = .43$).

Overall, transactive memory script improved quality of both joint and individual problem solution plans in newly-formed multidisciplinary learning dyads (hypothesis 2b).

3.4. The mediating impacts of the TMS on the effects of a transactive memory script on quality of learners' joint and individual problem solution plans (hypothesis 3)

First, the independent factor "transactive memory script" had a significant impact on the joint, $b = .79$, $t(26) = 3.02$, $p < .01$, and individual, $b = .50$, $t(26) = 2.15$, $p < .05$, problem solution plans. Transactive memory script explained a significant proportion of variance of joint, $R^2 = .26$, $F(1, 26) = 9.09$, $p < .01$, and individual, $R^2 = .15$, $F(1, 26) = 4.62$, $p < .05$, problem solution plans.

Second, the independent factor "transactive memory script" was a significant predictor of the mediator variables specialization, $b = .40$, $t(26) = 13.30$, $p < .01$, and coordination, $b = -.31$, $t(26) = -11.46$, $p < .01$. Transactive memory script explained a significant proportion of variance of specialization, $R^2 = .87$, $F(1, 26) = 176.83$, $p < .01$, and coordination, $R^2 = .83$, $F(1, 26) = 131.38$, $p < .01$. Transactive memory script was not significant for the mediator variable trust, $b = .02$, $t(26) = .67$, $p = .51$, and therefore trust was dropped from subsequent regression models.

Third, the specialization, $b = 1.97$, $t(26) = 3.29$, $p < .01$ and coordination, $b = -2.16$, $t(26) = -2.71$, $p < .05$, predicted the quality of joint problem solution plans. Specialization, $R^2 = .29$, $F(1, 26) = 10.80$, $p < .01$, and coordination, $R^2 = .22$, $F(1, 26) = 7.32$, $p < .05$, explained a significant proportion of variance of quality of joint problem solution plans. The regression analyses did not reach statistical significance with regard to the impact of specialization, $b = .89$, $t(26) = 1.55$, $p = .13$, and coordination, $b = -1.26$, $t(26) = -1.76$, $p = .09$, on the quality of individual problem solution plans, and therefore this was dropped from subsequent regression models.

For specialization, when the independent factor was included simultaneously in the regression model, the impact of the transactive memory script on the quality of joint problem solution plan was no longer significant, $b = .04$, $t(26) = .05$, $p = .95$. A Sobel test also confirmed that the impact of the transactive memory script on quality of joint problem solution plan was mediated by the specialization aspect of the TMS during discourse, $SEb = .60$; $b = 1.97$; $tSobel = 3.18$; $p < .01$.

There was a mediation effect for the coordination aspect of the TMS, but it was smaller than for specialization. When the independent factor was included simultaneously in the regression model, the impact of the transactive memory script on the quality of joint problem solution plan was no longer significant, $b = .75$, $t(26) = 1.15$, $p = .26$. A Sobel test confirmed that the impact of the transactive memory script on quality of joint problem solution plan was mediated by the coordination aspect of the TMS during discourse, $SEb = .80$; $b = -2.16$; $tSobel = 2.63$; $p < .01$ (see Fig. 1).

Overall, the specialization and coordination aspects of the TMS were mediators for the impacts of the transactive memory script on the quality of joint but not individual problem solution plans. The trust aspect of the TMS was not a mediator for the impacts of the script on the quality of joint and individual problem solution plans (hypothesis 3).

4. Discussion

Implementation of a transactive memory script in the form of prompts appeared to facilitate the TMS in multidisciplinary CSCL setting (hypothesis 1). The specialization of the knowledge along with recognition and awareness of expertise distributed in the group during the encoding process played an important role in coordinating problem-solving activities. Subsequently, assigning responsibility based on awareness of this specialized knowledge, and that individual's acceptance of the responsibility, helped coordinate the process of problem-solving by directing learners' focus to parts of the task that they had the most expertise for. These task coordination activities helped group members work effectively with a great sense of collaboration. That is why we found a substantial correlation between specialization and coordination aspects of the TMS in this study. Finally, prompts for combining individual solutions helped learners to consider both complementary areas of expertise, to retrieve required knowledge from

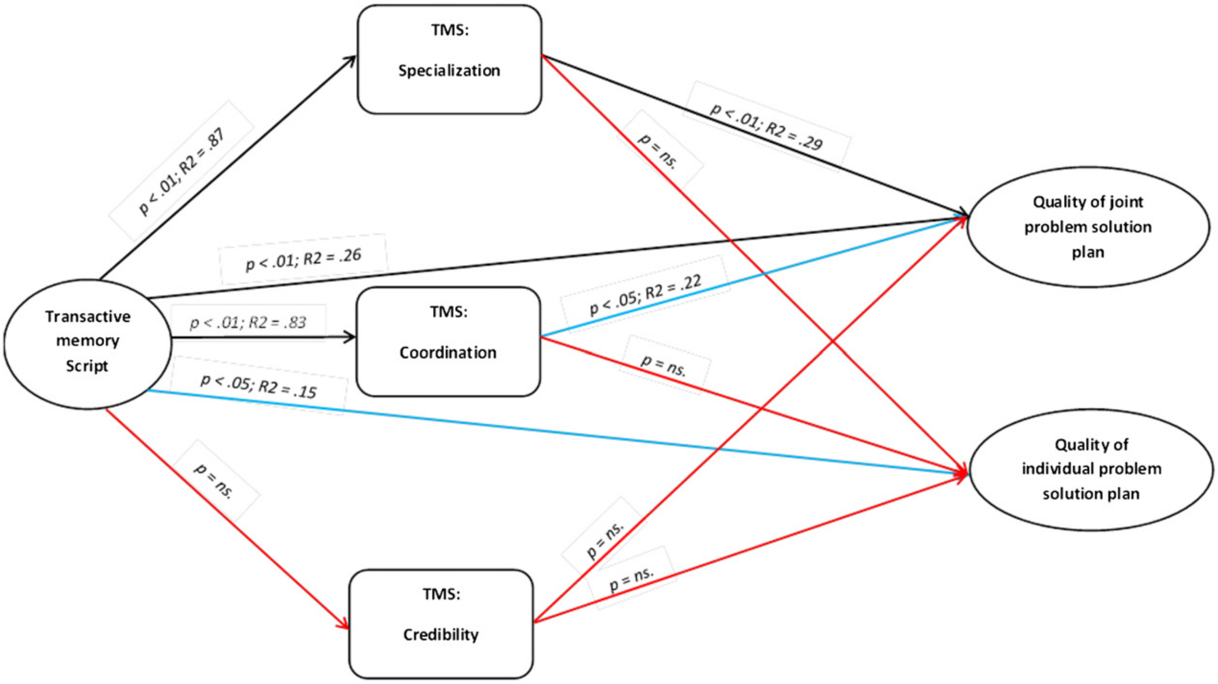

Fig. 1. A graphical representation for the results of the regression equation models. Black arrows indicate significance at the .01 level. Blue arrows indicate significance at .05 level. Red arrows indicate no significance. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the sources of expertise who had the stored information, and to arrive at a joint solution for the problem case (Rulke & Rau, 2000; Wegner, 1987). Appropriate coordination of the learning activities by assigning and acceptance of responsibilities could in turn impact the specialization aspect of the TMS in a group. The reason is that group members provide relevant information on the topic and analyse parts of the task based on assigned tasks and roles in relation to their specialized domains of expertise. As a result, group members effectively pool unshared information from their learning partners based on a heightened awareness of distributed knowledge resources in the group (Rummel et al., 2009).

According to the learners' responses to our questionnaire (Lewis, 2003), trust is indirectly influenced when the other two aspects are facilitated by a script. When learners read and analysed one another's portfolios, they understood that the complementary expertise for solving the problem case was located within the domain expertise of their learning partner. Having meta-knowledge about the domain expertise of their learning partner created a level of trust among individuals in the learning dyads (Wegner, 1987). Learning groups with a high level of trust have more opportunities to increase the entire team's knowledge stock based on awareness of the individual members' expertise (Henry, Strickland, Yorges, & Ladd, 1996), which can also result in better coordination with fewer social conflicts among members than learning groups with a low level of trust (McEvily, Perrone, & Zaheer, 2003).

Implementation of a transactive memory script did not facilitate individual-to-group knowledge transfer (hypothesis 2a). Due to the multidisciplinary nature of the learning task, learners in both conditions needed the complementary expertise of their learning partners to jointly make sense of the learning task. As a result, it could be that learners inclined to immediately accept rather than oppose the contributions of their partners while working on the joint problem solution plan. In both conditions, learners might have seen themselves as less competent than their partners regarding the latter's specialized expertise. This could also happen when learners want to manage the interaction and continue the discussion in terms of other aspects of the task and not because they are convinced (Weinberger & Fischer, 2006).

Implementation of a transactive memory script did facilitate group-to-individual knowledge transfer and knowledge convergence (hypothesis 2a). This is because the formation of a collaboratively shared system for encoding, storage, and retrieving knowledge fosters the integrative usage of information from a well-constructed TMS in the group. Creating such a TMS is effective when learners use their meta-knowledge awareness not only for coordinating subtasks and the division of labour/roles, but also for converging knowledge and transactions of unshared information (i.e., elicitation, externalization and giving specialized feedback).

As discussed earlier, scripted learners were able to extract more unshared information through elicitation, externalization, and giving specialized feedback than unscripted learners. These transactions amounted to a successful exchange of unshared information among group members in a collaborative problem-solving setting (Weinberger et al., 2005). As a result, scripted learners were able to engage in deep cognitive processing for learning and discovering complementary knowledge of the learning partner (Dillenbourg, 1999) that could also be applied for designing similar problem solution plans in the subsequent learning task. For this reason, scripted learners were able to converge their complementary knowledge and transfer the theoretical concepts from group representation into their individual posttest representations. In contrast, unscripted learners may have used their complementary knowledge only for coordinating subtasks and the division of labour/roles and not for integrative usage of information (Dillenbourg, 1999). Specifically, they just divided the task and individually took responsibility for part of the task based on their own expertise, and then assembled the partial results into the final output without further discussions, clarification, and/or elaboration of the learning material. As a result, unscripted learners were not able to transfer the domain expertise contributions of their learning partners to their individual representations in the posttest.

Implementation of a transactive memory script improved the quality of both collaborative and individual problem solution plans (hypothesis 2b). This finding corroborates other research results which showed a positive impact of a TMS on performance in collaborative settings (e.g., Moreland et al., 1996; Stasser et al., 1995). In collaborative problem solving, groups whose members are aware of one another's knowledge 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). Furthermore, having meta-knowledge about the domain expertise of learning partner(s) fosters the distribution of the task and coordination of distributed knowledge (Wegner, 1987), which in turn results in successful transactions among learning partners (e.g., Rummel & Spada, 2005; Stasser et al., 1995). These transactions, for examples, externalization and elicitation, have been regarded as important for improving learning performance (e.g., Fischer et al., 2002).

Contrary to most research studies on TMS, which mostly report on learning in relation to group performance (e.g., Michinov & Michinov, 2009; Moreland et al., 1996), this study presents separate data on the quality of individual problem solution plans. Similar to a study by Prichard, Stratford, and Bizo (2006), the findings of the current study support the positive effects of a TMS on individual performance. However, as assumed by Prichard et al. (2006), group members may employ strategies that enhance their group product, which is not necessarily the same as individual performance (Prichard et al., 2006). This implies that success in group performance does not always mirror individual performance. 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). That is why in a study by Hollingshead (1998), a group-to-individual transfer was not reported, indicating that group training on task practice improved group but not individual performance. As found in a study by Lewis, Lange, and Gallis (2005), the TMS transfers across tasks; hence groups with a strong TMS develop it further on subsequent tasks. Such a transfer was shown to happen when group members maintain the same division of cognitive labour and roles across tasks (Lewis et al., 2005). In the current study, this division of labour and roles was taken away in the subsequent individual task. Since the individual posttest was conducted immediately after the collaborative phase with an identical problem case, the difference in the quality of individual problem solution plan between scripted and unscripted learners still remained significant for the subsequent task. This difference was, however, less than the difference between scripted and unscripted learners for the group product. This individual difference may not have been achieved if the individual posttest had been conducted some time later with a rather different task. Therefore the impact of the transactive memory script was higher for collaborative than individual problem solution plans. Construction of a TMS in the group, with increasing specialization, 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 tasks that need complementary expertise and have to be solved individually without the presence of the domain expertise of the learning partner.

Various aspects of the TMS had an impact on the group product. This is in line with other research findings showing the impacts of the TMS on group performance (e.g., Moreland et al., 1998; Schreiber & Engelmann, 2010). Furthermore, the "specialization" and "coordination" aspects of the TMS significantly conveyed the influence of the transactive memory script on the quality of joint but not individual problem solution plans (hypothesis 3). This result indicates that the transactive memory script improved the quality of joint problem solution plans primarily by fostering the specialization and coordination aspects of the TMS among group members. Specialization and coordination help learners elaborate on the learning material, integrate and synthesize one another's perspectives and ideas in order to jointly make sense of the learning task (Fischer et al., 2002; Schoor & Bannert, 2011). They make integrative usage of meta-knowledge (Dillenbourg, 1999), resulting in higher quality of joint problem solution plans. However, the TMS did not convey the influence of the transactive memory script on the quality of individual problem solution plans (hypothesis 3). As discussed earlier, in the individual task, the division of labour and roles was taken away; and in such a situation the construction of a TMS would not be as effective as in a situation in which the group members maintain the same division of cognitive labour and roles across tasks (Lewis et al., 2005).

5. Implications, limitations, and suggestions for future research

Based on this study, the general conclusion can be drawn that not only concept maps (e.g., Schreiber & Engelmann, 2010) in CSCL environments but also implementation of a transactive memory script in the form of prompts can positively foster the construction of a TMS in a multidisciplinary setting. Furthermore, facilitation of a TMS not only improves learners' group-to-individual knowledge transfer and knowledge convergence but also fosters the quality of their joint product. At this point, it is relevant to discuss some strengths, weaknesses, and implications of the present study.

This study used a mixed approach to analyse the TMS, since such an approach for measuring the TMS has been recommended in the scientific literature (e.g., Moreland et al., 2010). We employed a validated questionnaire instrument (Lewis, 2003) and adapted it to fit the purpose of this study. The inter-rater reliability and values of this instrument have been reported as being satisfactory (e.g., London et al., 2005), and these values were even higher in the present study. We also developed a content analysis scheme and looked at the interaction data during collaborative discourse to measure the construction of various aspects of the TMS. Based on the results of the questionnaire (Lewis, 2003), the transactive memory script facilitated all three aspects of the TMS (specialization, coordination, and trust). The same results were also achieved on the basis of the collaborative discourse analysis, except for the trust aspect. The reason is that this aspect was not explicitly targeted by the transactive memory script introduced in this study. Based on Lewis (2003), we assumed that credibility or trust would be facilitated by the other two aspects of the TMS, namely specialization and coordination. However, this was not confirmed based on the content analysis coding scheme as opposed to the questionnaire instrument developed by Lewis (2003). This slight difference could be an effect of social desirability bias inherent in self-reporting responses, such as those elicited by a questionnaire (Huber & Power, 1985). Although the confidentiality of the responses was assured to eliminate such a potential bias, this might not exclude the possibility of learners coming up with answers that would be seen as desirable. To mitigate this effect in measuring the TMS, we therefore also analysed the discourse activities during the collaborative phase.

In this study we operationalized trust as the extent to which learners incorporated one another's theoretical concepts that were discussed during discourse into their joint problem solution plan. However, there could be some other factors that may potentially influence the inclusion of a proportion of concepts from a person's contributions into the joint solution. These factors include the quality, the extent, and the total number of concepts a person contributed, as well as the independent of that person's dominance or rhetoric skills, argumentation competence, persuasiveness, and negotiation skills. Further analysis needs to determine the extent to which each of these factors separately and in combination influence the transition of learning partners' theoretical concepts that are discussed during discourse into their joint problem solution plan. We therefore advise that follow-up studies be aimed at this question.

In this study we operationalized the theory of the TMS in a multidisciplinary setting that lasted a relatively short time. This is important since TMS is typically described based on relatively long-term collaboration within groups; and TMS is seen as something that continually develops and increases over the history of a group. We chose the shorter setting in order to investigate whether media-specific affordances in online collaboration, e.g., a CSCL script, could be designed to facilitate the construction of the TMS without longer-lasting interaction. Now that we know that the CSCL script can be designed for facilitation of the TMS in multidisciplinary settings in a rather short time period, we advise that follow-up studies test the impacts of such a script on construction of the TMS over a relatively long period of time. This could have consequences not only for the design principles of the CSCL scripts in relation to various aspects of the TMS, but also for the knowledge transfer from individuals-to-group and also group-to-individuals in a long-term study.

The collaboration in this study was realized in the form of dyads. 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 triads or larger groups (see Noroozi, Biemans, et al., 2012; Noroozi, Weinberger, et al., 2012). Communication difficulties therefore increase with group size (Steiner, 1972). This is especially important with respect to the construction of the TMS, since it may take longer for learners to efficiently establish their TMS for improving their performance in larger than in smaller groups. This is why in the study by Michinov and Michinov (2009), dyads and triads differed in the way the specialization aspect of the TMS influenced enhancement of performance. It would be insightful to test and accordingly adjust the effects of a transactive memory script on various aspects of the TMS in different-sized groups in order to maximize the likelihood of successful learning.

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