MUPEMURE: Towards a Model of Computer-supported Collaborative Learning with Multiple Representations

Organizers
Daniel Bodemer, University of Tübingen, Applied Cognitive Psychology and Media Psychology,
Konrad-Adenauer-Str. 40, 72072 Tübingen, Germany, d.bodemer@iwm-kmrc.de
Manu Kapur, National Institute of Education, 1 Nanyang Walk, 637616 Singapore, manu.kapur@nie.edu.sg
Gaëlle Molinari, Distance Learning University Switzerland, Centre d'Etudes de Sierre, TechnoArk 5,
Case postale 218, 3960 Sierre, Switzerland, gaelle.molinari@unidistance.ch
Nikol Rummel, Institute of Education, Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum,
Germany, nikol.rummel@rub.de
Armin Weinberger, Department of Educational Technology, Saarland University, Campus C 5.4,
66123 Saarbrücken, Germany, a.weinberger@mx.uni-saarland.de

Participants
Daniel Bodemer, University of Tübingen, Germany, d.bodemer@iwm-kmrc.de
Manu Kapur, National Institute of Education, Singapore, manu.kapur@nie.edu.sg
Gaëlle Molinari, Distance Learning University, Switzerland, gaelle.molinari@unidistance.ch
Armin Weinberger, Saarland University, Germany, a.weinberger@mx.uni-saarland.de
Katharina Westermann, Ruhr-Universität Bochum, Germany, katharina.westermann@ruhr-uni-bochum.de

Discussant
Kristine Lund, CNRS, University of Lyon, France; kristine.lund@univ-lyon2.fr

Abstract: The aim of this symposium is to advance an integrated framework—MUltiple PErspectives on MUltiple REpresentations (MUPEMURE)—for deriving understandings of how CSCL learners generate, share, and navigate multiple representations. We propose to achieve this by exploring synergies between the two bodies of research: learning with multiple external representations (MERs) and CSCL. Research on learning with MERs has the potential of providing useful insights when applied to understanding how CSCL learners generate and work with multiple external representations. Concomitantly, CSCL research has the potential of enhancing the design and explanatory framework of a body of research that has so far largely remained concerned with individual learning. We ground our discussion in four projects that explore different aspects of how CSCL learners can be supported to actively generate, share, and navigate multiple representations and acquire multiple perspectives through specific collaborative designs.

CSCL is Learning with Multiple Representations

When students collaborate in a CSCL environment dedicated to the learning of a complex science topic, they are confronted with multiple forms of external representations (such as texts, diagrams, graphs, equations, etc.) of the topic, and/or they may be asked to collaboratively construct different external representations.

Although there are potential benefits to giving learners the opportunity to interact with multiple external representations (MERs), translating between multiple external representations and mentally integrating them is a difficult and cognitively demanding task (Ainsworth, 2006; Schnotz & Bannert, 2003). In the context of individual learning, research suggested various methods to support learning with MERs: by reducing demanding visual search processes (e.g., Kalyuga, Chandler, & Sweller, 1999) or by directly initiating germane translation processes between MERs (e.g., Bodemer, Plötzner, Feuerlein, & Spada, 2004).

In the context of CSCL, however, research that focuses on the features and demands of MERs is in its infancy. For example, it has been investigated how different representational tools might support collaborative learning (e.g., Suthers & Hundhausen, 2003). Not much research has, however, focused on the complementary question: how computer-based learning with MERs can be encouraged and promoted by collaboration (e.g., Kozma, 2003) and how translation processes between MERs and between learners can be supported during CSCL (Bodemer, 2011).

The main aim of this symposium is to pick up this thread of research on learning with MERs in CSCL and to enrich the so far scarce body of literature with new findings and approaches on MERs and CSCL. We believe —and aim to discuss in this symposium—that learning with multiple perspectives on multiple representations is deeply engrained in CSCL settings, and that CSCL can benefit from taking (research on) multiple representations into account. In doing so, we advance an integrated framework for better understanding of how collaborative CSCL learners share, process and acquire multiple perspectives on multiple external representations (a MUltiple PErspectives on MUltiple REpresentations—MUPEMURE model). One way to develop such a framework is to explore potential synergies between the two bodies of research: individual learning with MERs and CSCL.

In research on individual learning with MERs, three main research perspectives have been identified (see Schnotz & Kürschner, 2008). The first two perspectives focus on how learners use different forms of external representations in isolation and/or in interaction with each other to build internal mental models. The third perspective concerns the relationship between MERs and internal (mental) multiple representations in the process of learning. A general theoretical framework—the Design, Function, Tasks or DeFT framework—has been developed by Ainsworth (2006) to examine learning designs that exploit learning with MERs. It also provides a useful lens for understanding how can learners be supported to use MERs in ways that facilitate learning. The DeFT framework examines the *design parameters* (i.e., number/form/sequence of external representations, distribution of information between the representations, support for translation between representations), the *specific functions* of MERs (i.e., to complement or constraint each other with regard to their interpretation, to support the construction of deeper understanding), and the *cognitive tasks* that learners need to engage in when interacting with MERs (i.e., to understand how to coordinate and integrate MERs). In doing so, the DeFT framework goes beyond theories that emphasize and focus on the representational form of information, and proposes a broader set of criteria for designing for learning. At play is an ecology of sensory-motor, perceptual (e.g., attending to, noticing, apprehending, etc.), and cognitive (e.g., organizing, elaborating, explaining, relating, translating, etc.) mechanisms that need to be supported as learners interact with MERs.

However, research on learning with multiple representations has largely remained focused on individual cognition and learning. We argue to extend and apply this research to CSCL settings because CSCL requires learners to construct, share, and work across multiple representations. Furthermore, CSCL with MERs also comprises the very perceptual and cognitive mechanisms at the individual level, but these are dialectically coupled with the additional mechanisms (and burden of) coordination and inter-subjective meaning making of multiple learners bearing multiple perspectives. CSCL with MERs then needs to analyze the back and forth translation between multiple internal and external computer-supported representations of multiple learners (see Figure 1).

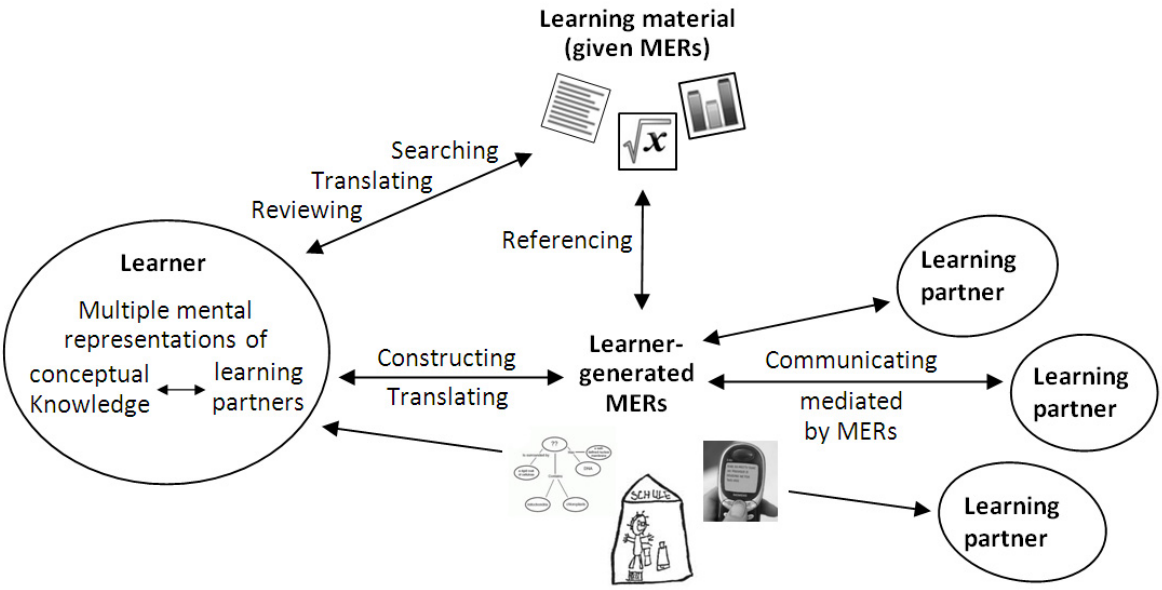

Figure 1. Model of MUPEMURE (Multiple Perspectives on Multiple Representations).

Figure 1 depicts learners who have or are meant to have diverging perspectives on these representations. Resolving the multiple perspectives and converging upon a shared representation has been argued to mediate individual learning (Roschelle, 1992; Weinberger, Stegmann, & Fischer, 2007). MERs may then have different functions for CSCL. For instance, multiple representations may serve to set up CSCL in a way that different learners possess different representations to engage in joint reasoning when resolving inconsistencies and translating between the representations (Slof, Erkens, Kirschner, Jaspers, & Janssen, 2010). MERs take on additional importance in CSCL because these representations are also the medium of communication (Lund, Molinari, Séjourné, & Baker, 2007; Suthers & Hundhausen, 2003). There are, however, also indications that building on multiple representations to share understanding and to convey a complete picture of a phenomenon is difficult for students in comparisons to experts (Kozma, 2003). Against the background of cognitive load theory, it has therefore been argued that co-constructing MERs should be avoided in favor of worked-out external representations (van Bruggen, Kirschner, & Jochems, 2002). Alternatively, there are also approaches to facilitate sharing and translating between multiple perspectives within CSCL, such as group awareness tools (Bodemer & Dehler, 2011; Buder & Bodemer, 2008) and CSCL scripts (Fischer, Kollar, Mandl, & Haake, 2007; Rummel & Spada, 2005; Weinberger, Stegmann, & Fischer, 2010). In sum, carefully arranging multiple representations to convey multiple perspectives of a phenomenon or as communication media for suggesting learners to engage in specific CSCL activities can be regarded an approach to foster CSCL per se. Simultaneously, coordinating and translating between multiple representations, and ultimately converging upon shared representations can also be regarded a challenge for which particularly computer-supported collaborative learners may need additional support in form of CSCL scripts and group awareness tools.

An important theoretical and empirical opportunity beckons: Research on learning with MERs and the DeFT framework have the potential of providing useful insights when applied to understanding how CSCL learners generate and work with multiple external representations. At the same time, CSCL research has the potential to enhancing the design and explanatory framework of a body of research that has so far largely remained concerned with individual cognition and learning. It is precisely the abovementioned opportunity that this symposium aims to explore.

Structure of the Symposium

We will initiate the symposium with a brief presentation of the proposed MUPEMURE model. Four projects highlighting different aspects within the envisioned MUPEMURE model will then be introduced briefly. Although the four studies involve participants across several age groups and subject domains, what is invariant across the studies is that all four are concerned with how learners individually and collaboratively construct and learn with MERs. What varies across the projects is the manner in which learners can be supported in the process of learning with MERs. More specifically, Project 1 explores the problem of translating between multiple *self*-generated representations, and constitutes a departure point for balancing CSCL support for learners to either fail or succeed in a way that is productive for learning (Kapur, 2009; Kapur & Rummel, 2009). In Project 2, computer-supported collaborative learners have to translate between multiple external representations and are supported by a group awareness tool to do so. The group awareness tool builds on shared visualization of individual task accomplishments of the spatially distributed learners. In Project 3, learners need to explicitly translate between different representations and from individual to collaborative learning phases. This aspect is continued in Project 4, in which students are either made aware of specific aspects of multiple peer- or self-generated drawings of science phenomena or are scripted to first construct an individual drawing and then to systematically compare the drawing with a drawing of a peer, and point out and resolve differences between the drawings.

For each of these projects, we discuss how learners of different age groups generate representations, how these representations facilitate as well as constrain attention, interpretation, and perspectival plurality, how the socio-cognitive processes and mechanisms embodied in the collaborative designs afford opportunities for explanation, elaboration, inter-subjective meaning making, and constructing deeper understanding, and how learners can be supported to do so productively by making learners aware of multiple perspectives of the multiple representations or by scripting learners to engage in activities of comparing and translating between multiple representations. Finally, the discussant of this symposium, Kristine Lund, will relate to and critically comment on the MUPEMURE model and the different vistas opened up by the empirical work shared in this symposium. Finally, we aim to advance the model by involving the audience in a critical discussion aiming towards an adaption of the model.

What Type of Support is Needed When Students Generate Multiple Representations in Small Groups?

Katharina Westermann & Nikol Rummel

Research on productive failure has demonstrated that students can learn from unsupported problem-solving in small groups followed by a teacher-led consolidation phase (e.g. Kapur, 2009). More specifically, in the productive failure design, students first collaboratively engage in unsupported problem-solving, generating a diversity of representations as they try different solution approaches. In the subsequent consolidation phase, the generated representations are compared and contrasted in a teacher-led discussion before the teacher finally presents the canonical solution. Thus, at first glance, productive failure looks like an approach without any support during the first phase. However, upon closer inspection in the productive failure studies teachers in fact do provide some motivational or cognitive support during the "unsupported" collaborative problem-solving phase. This leads to the question whether students need at least a minimum of guidance during this phase. Kapur and Rummel (2009) have argued that structuring the learning process from the beginning can either lead to productive success or to an illusion of performance without learning (unproductive success) whereas delaying structure may result in productive or unproductive failure. In line with this differentiation, we argue in our project that different support types should be distinguished (Rummel & Westermann, 2010) and it remains to be studied which elements of support are needed to make the experiences of failure during the collaborative problem-solving phase productive.

In earlier studies on productive failure (Kapur, 2009), students only received motivational support to persist in generating different representations during the unsupported problem-solving phase. In current studies by Kapur, students are prompted to critically reflect about the representations they generated in order to improve their solution approach from one representation to the next. However, the differences between the former and the latter studies were so far not investigated empirically. To close this empirical gap, we compare two conditions with different support types during the "unsupported" collaborative problem-solving phase: Students in the standard *productive failure* condition (PF) receive motivational support encouraging them to persist in solving a new mathematical problem (e.g. "it is okay to struggle with the problem"; "you are doing a good job"). In the *augmented productive failure* condition (PF+), students additionally receive cognitive prompts, that is, students are supported in their critical evaluation of the representations they generate (e.g. "maybe there are situation where your solution does not work, have a look at this counter-example"). In both conditions, students are expected to try different solution approaches during the problem-solving phase by generating different representations, such as tables, graphs and formulas. Students use tablet PCs to generate, share and discuss representations. Following the productive failure paradigm, the collaborative problem-solving phase is followed by a consolidation phase where the student-generated representations are compared and contrasted in a teacher-led discussion before the teacher finally presents the canonical solution. Also, parallel to Kapur's studies, in addition to the two productive failure conditions, we implement a *direct instruction condition* (DI) that serves as a control condition. In the direct instruction condition the teacher explains the concept and introduces the canonical solution of the mathematical problem by using different representational formats, before the students solve practice problems in small groups.

Learning outcomes are assessed by an intermediate test after the first phase (collaborative problem-solving or instruction by teacher) and by a posttest after the second phase (consolidation phase or solving of practice problems) to measure the effects of both phases separately. In addition, we implement a two-week delayed posttest. The tests include retention items, conceptual items that test for deeper understanding, and transfer items. Process data recorded from the tablet PCs and audio recordings will enable a detailed analysis of how students generate representations individually and in the group, and how they make connections across representations while being facilitated in different ways. Participants are 170 10th graders recruited from two secondary schools in Bochum, Germany.

We hypothesize that the combined support in the PF+ condition best supports students in structuring and developing their ideas and will thus lead to better learning outcomes compared to the PF condition or the DI control condition. Following the discussion of Kapur and Rummel (2009), the PF condition without cognitive support may mark the line between productive and unproductive failure and therefore may or may not outperform the DI condition. The results of the study are presented and discussed at the conference.

Table 1: Conditions of the study.

	Phase 1	*Phase 2*
PF	Problem-solving in small groups with motivational prompts	Teacher-led compare and contrast, presentation of the canonical solution
PF+	Problem-solving in small groups with motivational and cognitive prompts	Teacher-led compare and contrast, presentation of the canonical solution
DI	Instruction and presentation of the canonical solution	Problem-solving in small groups

How Can Group Awareness Tools Tacitly Guide Collaborative Learning with Multiple Representations?

Daniel Bodemer

A main requirement in developing a tool that supports collaborative learning with multiple external representations is the simultaneous consideration of both individual and collaborative processes. In this research project, facilitating group awareness is proposed as a suitable means for reducing unprofitable collaborative effort, and for tacitly guiding learning-relevant interactions while leaving the scope for individual learning processes and their support. Group awareness is an emerging topic in CSCL-research (Bodemer & Dehler, 2011). It covers the knowledge and perception of behavioral, cognitive, and social context information on a group or its members. A central aim of CSCL-related research on group awareness is the development of tools that tacitly guide learners' behavior, communication, and reflection by the presentation of information on a learning partner or a group. Group awareness tools particularly qualify for being combined with support methods for individual MER-related learning processes because of their representational nature and because they do not restrain individual self-regulated learning processes.

Accordingly, a group awareness tool (collaborative integration tool) was developed and experimentally evaluated that is intended to support collaborative learning with MERs (Bodemer, 2011). It is based on the instructional task *active integration* that has repeatedly been shown to foster meaningful learning processes during individual learning with multiple external representations (e.g., Bodemer et al., 2004; Bodemer & Faust, 2006). The tool enables two spatially distributed learning partners to simultaneously integrate components of differently represented learning material on computer screens. Learners are provided with a shared visualization that contains the current state of integration of both learning partners (see Figure 2).

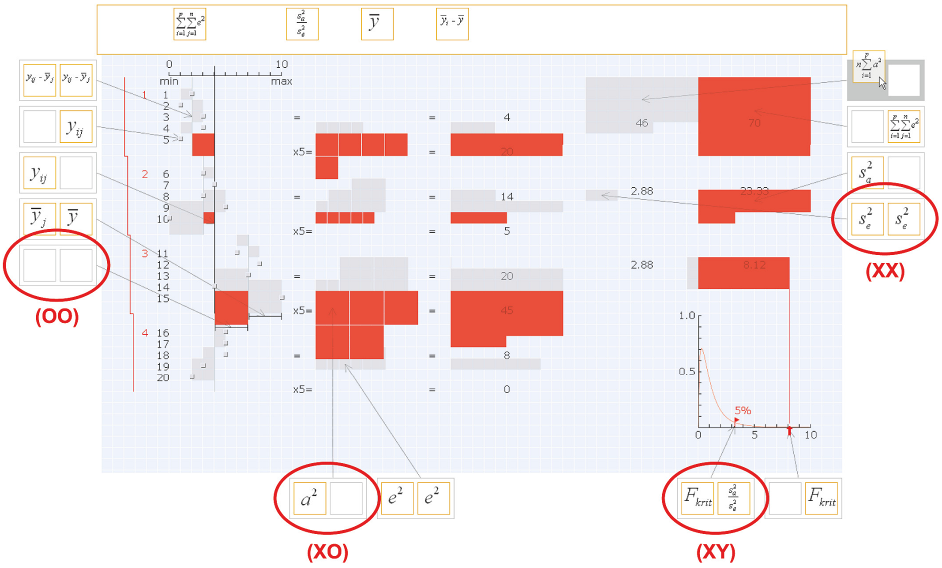

Figure 2. Collaborative integration of multiple external representations during learning statistics. Two learning partners simultaneously drag algebraic components onto the drop areas adjacent to the visualization (learner A's assignments on the left side of each drop area, learner B's assignments on the right side). Four basic cases of knowledge distribution are highlighted.

While interactively integrating different sources of information is intended to support individual elaboration processes by means of external and mental structure mapping, there are other supporting functions that address the collaborative scenario, such as reducing extraneous grounding costs or structuring the learning discourse on the basis of the externalized knowledge distribution (e.g., discussing conflicting knowledge constellations).

The collaborative integration tool was experimentally compared to an integration tool without awareness component (study 1) and to a joint integration condition (study 2). In both studies university students were paired into dyads discussing statistics concepts underlying the one-way analysis of variance. It showed that providing group awareness during collaborative learning with multiple external representations can lead to better individual learning gains by reducing demanding processes and by tacitly guiding learner interactions (Bodemer, 2011). Analyses of the learners' interactions revealed that learners with group awareness support were more involved in meaningful discussions and spent less time for extraneous grounding and modeling processes. Moreover, it showed that learners adapted their discussion behavior to their awareness of knowledge distributions (i.e., talking about perceived conflicting perspectives in a more interactive way).

How Do Co-Learners Build a Collaborative Concept Map Using Visualizations of Their Either Similar or Complementary Prior Knowledge?

Gaëlle Molinari, Mirweis Sangin, Marc-Antoine Nüssli, & Pierre Dillenbourg

In the present contribution, we report an exploratory analysis of how co-learners with either similar or complementary prior knowledge use and articulate their personal knowledge maps in a collaborative concept-mapping task. Concept mapping is a technique that can be used for the visualization of knowledge in both individual and collaborative learning settings. Concept-map building positively contributes to the learning process and triggers positive attitudes among learners by making them aware of their misunderstandings (e.g., Horton, McConny, Gallo, Woods, & Hamelin, 1993). Other research (e.g., Lund et al., 2007) explored concept mapping in CSCL activities and showed that the collaborative construction of concept maps creates opportunities for knowledge externalization and negotiation of meaning.

In a previous study presented at the ICLS conference 2008, Molinari, Sangin, Nüssli, and Dillenbourg (2008) focused on visual and action transactivity in collaborative concept mapping. In this study, university students collaborated remotely in dyads; they were asked to build a joint concept map to visually represent their shared understanding of a science topic (the neuron physiology). While building the collaborative map, peers were provided with visualizations (in the form of personal concept maps) of both their own- and their partner's prior knowledge. Personal knowledge maps were constructed by learners themselves after the reading of a text (on the neuron) in a first individual learning phase. Two eye-trackers were used to record peers' eye movements during the course of collaboration. The aim was to investigate how co-learners distributed their visual attention across the three concept maps (collaborative map, own- and partner's personal maps). In particular, the question concerned the extent to which peers visually referred to their partner's map while interacting together (visual transactivity). Action transactivity was also analyzed as being the degree to which co-learners manipulated their partner's contributions in the collaborative map. The other objective was to understand how a collaboration script designed to provide co-learners with either similar or complementary prior knowledge (knowledge interdependence script) could affect visual and action transactivity. In the individual learning phase, two conditions were designed. Both peers individually read the same text in the "Similar Knowledge" (SK) condition while each of them read one of two complementary texts in the "Complementary Knowledge" (CK) condition. The main results (Molinari et al., 2008) showed that peers focused twice longer on their own knowledge map in the CK condition than in the SK condition. There were also negative relations between learning performance and respectively the amount of time spent consulting the own map, the number of gaze transitions between the own- and the collaborative maps. No difference occurred in the extent to which co-learners visually referred to their partner's map between both conditions. Finally, there was a trend for the level of action transactivity to be higher in the SK condition than in the CK condition.

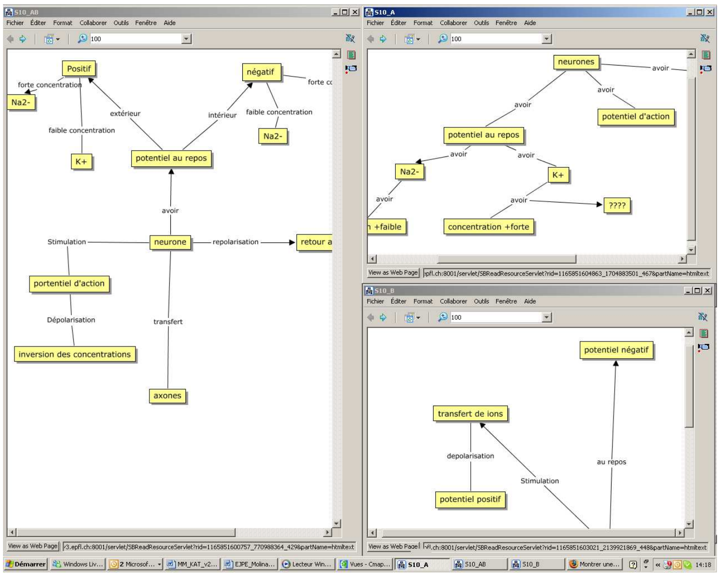

Figure 3. Collaborative phase (collaborative map on the left side, learner's own knowledge map at the top of the right side, partner's knowledge map at the bottom of the right side).

In the present contribution, we extended these previous results by investigating how co-learners used and coordinated visualizations of their respective prior knowledge (personal concept maps) to build the collaborative map. Here we focused on structural analyses of personal and collaborative maps; in particular, we analyzed the number of personal map elements (concepts and links) that have been selected and directly incorporated in the collaborative map. The number of new concept-map elements created during collaboration was also analyzed. Finally, we examined the relationships between characteristics of personal and collaborative maps, learners' visual behavior on the three concept maps, action transactivity, and learning outcomes. Another focus was on the effect of the knowledge interdependence script with the main hypothesis that co-learners will more likely to use and articulate their respective personal maps to construct the collaborative map when they shared complementary (CK condition) rather than similar prior knowledge (SK condition). On the one hand, results showed that the higher the number of elements in the personal maps, the higher the degree to which learners manipulated their partner's contributions in the collaborative map (action transactivity). Moreover, the higher the number of elements common to both personal maps, the less learners focused on their own map. The number of gaze transitions between the own- and the collaborative maps was also negatively correlated to the number of new concept-map elements created during collaboration. Finally, there was no relation between learning outcomes and the number of elements in both personal and collaborative maps. On the other hand, results showed that there was no difference between the SK and CK conditions with respect to the number of personal map elements directly incorporated in the collaborative map. All these results will be discussed in detail at the conference.

How Can Scripts and Awareness Tools Orchestrate Individual and Collaborative Drawing of Elementary Students for Learning Science?

Hannie Gijlers, Alieke van Dijk, & Armin Weinberger

Graphical representations have the potential to enhance elementary school students' science learning experiences by visualizing unseen and complex information and making abstract information more concrete and understandable (Rennie & Jarvis, 1995). However, the mere examination of representations at times leads to shallow processing of the material. By constructing their own representations of scientific phenomena learners are stimulated to identify and link important and relevant pieces of information and thereby engage in self-explanatory and reflective processes (Ainsworth & Loizou, 2003). Drawing has the potential to serve collaborative learning; it facilitates idea sharing and disambiguation of conceptual understanding. Drawings also allow students to easily inspect and build on the ideas represented by their partner and may help students to maintain a common focus (Suthers & Hundhausen, 2003). We argue that the introduction of computer based drawing tools eases the exchange, comparison, revision, and combination of learners' drawings. Support in the form of scripts, or scaffolds (such as awareness support) can easily be implemented or combined with computer based drawing tools.

The aim of this study is to investigate to what extent instructional support in the form of *awareness features* or *scripting* facilitates learning processes and outcomes of elementary school students who collaboratively construct drawings of science phenomena. In this study, awareness support is focused on learners' intermediate products, i.e. the highlighting of specific objects and characteristics (arrows, labels) represented in learners' drawings. The awareness feature provides feedback on the characteristics of learners' drawings in the form of prompts. Furthermore, a collaboration script will be implemented to support students in the process of discussing their individual drawings, mutually criticize and challenge their individual contributions and eventually arrive at a shared representation of the knowledge domain. Scripts have proven to be a powerful instructional approach to foster specific collaborative activities and interaction patterns, such as identifying conceptual differences, asking thought-provoking questions, integrating multiple perspectives, and / or constructing arguments and counter-arguments (Weinberger et al., 2010). We assumed that whereas the awareness support improves *what* learners consider in their collaborative drawings, the script improves *how* learners deal with the content.

To test these hypotheses, we realized a pre-post-test design with three experimental conditions: 1) Collaborative learning with a drawing tool (control condition), 2) Collaborative learning with a drawing tool with awareness feature (awareness condition), and 3) Scripted collaborative learning with a drawing tool (script condition). Ninety-four 6th grade elementary school students, aged 11-12 participated in the study. All students were paired into dyads with a student from their own school. Students used a computer based drawing tool to work on a drawing assignment on the topic of photosynthesis. Dyads were assigned to one of the three conditions described above. To measure the effect of the instructional interventions (awareness support or script), learning outcomes were assessed using an open recall and a cued recall domain knowledge test. Furthermore, intermediate as well as final drawings were scored. The results show that students supported with the awareness feature or the script demonstrated higher levels of knowledge acquisition on a cued recall test, $\chi^2(2, N = 90) = 19.80$, $p = .01$, as well as an open recall test, $\chi^2(2, N = 92) = 40.03$, $p = .03$, than their peers in the control condition. Furthermore, learners with awareness support drew and annotated less concepts, whereas the scripted learners drew and annotated concepts more than learners without script with the later difference being significant, $\chi^2(2, N = 44) = 66.89$, $p = .01$. The results will be discussed against the background of how collaborative drawing can facilitate elementary children's conceptual understanding and how collaborative drawing should be additionally supported to fully develop the benefits it can entail.

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