# Collaborative drawing on a shared digital canvas in elementary science education: The effects of script and task awareness support

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**Abstract** Creating shared representations can foster knowledge acquisition by elementary school students by promoting active integration and translation of new information. In this study, we investigate to what extent awareness support and scripting facilitate knowledge construction and discourse quality of elementary school students (n=94) in a computer-supported collaborative drawing scenario. Students in the awareness condition received feedback prompts based on the characteristics of their drawing. The script foresaw a sequence of creating, comparing, discussing, and merging individual drawings to arrive at a shared representation of the subject matter, which was photosynthesis. Both forms of support, (awareness and scripting) facilitated the learning processes and outcomes. Discourse analysis revealed that awareness and scripting increased (the share of) integrative and conflict-oriented consensus-building activities as well as (the share of) off-task and coordination-related activities in comparison to the control group. Awareness and scripting facilitated deeper understanding of the processes and relations of domain concepts. The scripted students acquired significantly more conceptual knowledge than the unscripted students.

Keywords Collaborative drawing · Scripting · Awareness

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#### Drawing in science education

Drawing is common practice and arguably an important way for elementary students to represent knowledge about their surroundings. Drawing, i.e., self-guided creation of graphical representations, has the potential to better enhance learning than simply presenting students with given representations (van Meter and Garner 2005). Some studies suggest that encouraging students to make drawings of scientific phenomena facilitates meaning making, scientific reasoning, and learning (Ainsworth et al. 2011; Brooks 2009). Brooks (2009) used a socio-cultural framework to examine the relation between elementary school students' drawing activities and their exploration of scientific ideas. Brooks showed that drawing can assist students in the exploration of scientific ideas and can assist them in their shift from naïve concepts to more scientific concepts. Furthermore, Ainsworth et al. (2011) explain that drawing can facilitate reasoning in science and stress that drawing can be an effective learning strategy that allows learners to integrate new information with their existing understanding of a domain and might even generate new inferences.

However, there are only few studies investigating how students can be supported to engage in productive drawing activities for enhancing comprehension of science texts (Leopold and Leutner 2012; Schwamborn et al. 2010; van Meter 2001). Drawing enhances students' visualization of concepts and ideas during the exploration of scientific models and scientific texts (Brooks 2009). The process of reconsidering elements from a drawing, revising, and discussing drawings enables students to process concepts and ideas from text, make connections and move toward higher levels of thinking and comprehension. The results of a study by Leopold and Leutner (2012) indicate that students who were instructed to create drawings of a science text about water molecules outperformed their peers who received text-based instruction. Leopold and Leutner (2012) performed two experiments in which they contrasted drawing-based learning with one of two more text-focused learning strategies (main idea selection in the first experiment and summarization in the second experiment). Students in the drawing condition were asked to draw a picture of each paragraph, students in the text based condition were asked to either select and write down the main ideas of each paragraph (exp. 1) or write a summary of each paragraph (exp. 2). In the combined condition, students used a drawing strategy as well as a text-focused strategy; students in the no-strategy condition were asked to study the text without further instruction. The results of both experiments showed positive effects of the drawing instructions and negative effects of the text-focused strategy instructions on students' performance on a multiple-choice test and a transfer test. Furthermore, the drawing strategy improved students' performance on a concept visualization test. Creating a drawing seems to support integration of new into existing knowledge structures, and construction of an elaborated mental representation of the concepts and relations that are discussed in the science text (Leopold and Leutner 2012). What is yet unclear, however, is to what extent students should be guided by structures or enabled by additional information to cognitively benefit from drawing for science learning.

Among the benefits for students graphically representing knowledge are the selfexplanation and the disambiguation of their mental models. When drawing, students need to elaborate the various concepts and relations between concepts of a topic and may identify and amend inconsistencies. This elaboration may be enhanced further if students are drawing in collaborative arrangements, i.e., when they are drawing with an addressee in mind or when they are drawing collaboratively. In the latter case, students may additionally benefit from sharing focus on the joint drawing task, which may in turn facilitate knowledge sharing and convergence (Weinberger et al. 2007). For instance, Roth and Roychoudhury (1993) illustrate how creating a shared representation in the form of a concept map enhances students' negotiation of meaning. Suthers and Hundhausen (2003) found that shared representations might serve as a group memory reflecting prior findings and ideas, which students can refer to and build on during the collaborative learning process. During the construction of a shared representation, students frequently discussed the nature of domain related relations, and referred to, and built on concepts introduced by their learning partner. Furthermore, with respect to the collaborative learning process, collaboratively constructed representations can offer students representational guidance. Suthers and Hundhausen (2003) for example argue that a shared representation might serve as a group memory, reflecting prior findings or ideas, which students can refer to and build upon during the collaborative learning process. Similar findings were reported by Gijlers and de Jong (2013) who studied the effect of a shared concept-mapping task on students' collaborative learning process. They found that students in the concept mapping condition more often re-used and referred to concepts and relations they had discussed at an earlier stage in their argumentation than their peers in the control condition.

In the process of creating a joint domain-related drawing, students are expected to discuss their ideas, negotiate meaning, and reach consensus concerning the knowledge and ideas that will be represented. Various qualities of students' interaction concerning how students relate to each other (transactive quality) and how students relate to the concepts to be learned (epistemic quality) have been linked to the outcomes of collaborative learning (Weinberger and Fischer 2006). With respect to how students relate to each other, there are indications that the more students build on the reasoning of their peers, the more they individually benefit from the collaborative learning arrangement (Teasley 1997). Contributions in which students' integrate their partners' ideas in their own reasoning or critically discuss their partners' contribution are considered highly transactive and are associated with positive learning outcomes.

An example of the effect of representational guidance is given by Gijlers et al. (2009) who have shown that the creation of a shared representation can facilitate transactive communication. Gijlers et al. re-analyzed the data from four studies that investigated the effect of different kinds of support for collaborative inquiry learning. Support varied from instruction in effective communication to different scaffolds aimed at supporting students' inquiry learning process, including the construction of a shared concept map. Gijlers et al. found that explicit instruction in effective communication as well as collaboration on a shared concept-mapping task facilitated transactive communication in comparison to tools that focused on supporting hypotheses generation. It was argued that shared concept mapping actually visualizes students' knowledge-building process and makes it easier for students to refer to and build on concepts and relations that were discussed at earlier stages of the learning process, and to include this knowledge in new arguments and explanations.

With respect to how students relate to the concepts to be learned, findings have shown that the mere externalization of domain related facts is not associated with knowledge acquisition (Anjewierden et al. 2011; de Vries et al. 2002). However, the exchange of, and explanation of information regarding domain related relations could enhance students' understanding of the domain (Anjewierden et al. 2011).

In spite of joint knowledge representations, students often seem to have difficulties engaging in interactions of both, high transactive and epistemic quality and may not always benefit from collaborative learning arrangements (e.g. Oortwijn et al. 2008; Saab et al. 2007; Tolmie et al. 2010; Webb and Mastergeorge 2003; Weinberger et al. 2005)

#### Supporting the collaborative drawing process

Students' (individual) knowledge construction as well as quality of collaborative discourse can be influenced by instructional support. Especially in computer-supported collaborative learning scenarios, support has been designed and investigated that is directed at the processes of students interacting with each other. For instance, collaboration scripts have been developed as process-oriented scaffolds for students to engage in specific roles and activities of higher epistemic and transactive quality (Weinberger et al. 2005).

Besides considering what aspects, transactive and/or epistemic, of students' interaction should be facilitated, it is yet unclear to what extent students should be guided by scripts to engage in high-quality interactions or whether students should be made aware of the respective qualities of their interactions to self-regulate their collaborative learning processes. The effect of scripting and awareness support have been studied in collaborative learning settings but up to this moment have not been investigated together with representational guidance provided by a shared drawing. In the present study, we investigate a collaboration script that guides students' collaboration, and awareness support that provides students with feedback on the content of their drawing.

### Scripting the collaboration

Collaboration scripts structure and sequence students' collaborative learning activities (Weinberger et al. 2001). Collaboration scripts are designed to shape the way students interact with each other in such a way that they will induce specific activities and discourse moves that are associated with learning. Basically, a script provides students with detailed and explicit guidelines about the task, and its successive subtasks, as well as the expected mode of collaboration within each subtask (Dillenbourg 2002). A classic example of scripted collaboration is provided by the MURDER script (Hythecker et al. 1988; O'Donnell and Dansereau 1992). In the collaborative MURDER script (the acronym stands for mood, understand, recall, detect, elaborate, review and describes the sequence) students prepare for the learning task. Students individually study the learning material, one student recalls and summarizes the learning material, while the other student tries to detect omissions and provides feedback. In the subsequent collaborative phase students elaborate by adding nodes and generating visualizations and examples to the learning material. In the next stage the roles of the students will alternate. Scripts (like the MURDER script) specify the sequence of individual and collaborative activities that students are expected to perform. By specifying the logistics of the collaboration (Scanlon et al. 2011) scripts alleviate students' need for coordinating activities (Weinberger 2011).

The structure provided by a script may result in more consistent levels of interaction and transactive discourse. Schellens et al. (2005), for example, report on the results of a study that investigated the effect of a role based script. Their findings show that the script not only improved the quality of students' argumentative discourse, but also facilitated students' knowledge acquisition. van Dijk et al. (in press) designed a script to support elementary school students during their collaborative drawing process. In their study students in the scripted condition outperformed their peers in the control condition on a conceptual knowledge test.

Despite the positive effects of scripting discussed above, there might also be some negative side effects of scripting. If students have highly developed procedural knowledge about how to interact, scripts may disturb students' interaction and problem solving process (Dillenbourg 2002). Scripts may work best whenever they prescribe a sequence of learning-

related activities that students' would normally not take up (for example, reviewing the contribution text of your partner, summarizing, or explaining). These activities are intended to positively influence students' interaction and learning process but also take extra time and effort (Weinberger 2011) and might be considered intruisive. Kollar et al. (2007), for example, argue that scripts, may interfere with students' personal (and potentially effective) ideas and procedures related to the completion of a collaborative learning task. Very detailed and restricting (coercive) scripts may also have a negative impact on students' motivation (Rummel and Spada 2005), and may reduce the opportunities for elaboration and critical discussion.

#### Awareness support

In the area of computer-supported collaborative learning, we can identify a number of various perspectives on "awareness", generally subsumed as students' perception and knowledge about a certain situation (Buder and Bodemer 2008) or as the "understanding of the activities of others, which provides a context for your own activity" (Dourish and Bellotti 1992). This may include knowledge and understanding of (inter) activities, other persons, groups, processes, tasks, tools or artifacts. On a general level, we can distinguish between *task awareness* and *group awareness* (Buder and Bodemer 2008; Fransen et al. 2011). Task awareness relates to students' knowledge and perception of the learning task (e.g., expected behavior, task progress). Group awareness relates to the knowledge and perception of the collaborative learning setting (e.g., level of participation, activities, and prior knowledge of the learning partner): "Group awareness is the up-to-the-minute knowledge of other people's activities that is required for an individual to coordinate and complete their part of a group task." (Gutwin and Greenberg 1995).

Awareness support aims at increasing awareness by providing information about the task or group processes that is otherwise covert or less salient. Based on that information, users are supposedly enabled to adjust their behavior, e.g., in terms of how they approach a group task, whenever they and their partners notice deviations from typically implicit (group) norms. Awareness support may be particularly beneficial in computer-supported collaboration, often characterized by low awareness of group processes, e.g., awareness on what subtasks partners are currently working on in a computer-mediated setting. Moreover, awareness support typically builds on data that can be subtly collected through logfiles and automatic analyses in computer-supported environments. Examples of awareness tools include energy monitors that provide information about the amount and costs of the energy used in a certain building or social navigation tools in online bookstores that inform customers about books that other customers with similar interest are reading.

Students are often not aware that they engage in learning processes or activities that do not contribute to successful completion of the learning task. The general goal of awareness support is to increase students' awareness of specific situations or processes so that they can use this information to adjust their learning activities. The Progress portfolio in the World watcher learning environment (Edelson 2001) is an example of a tool that supports task awareness. In the Progress portfolio students can capture, organize, and relate their observations to their initial hypothesis. In this way the Progress Portfolio supports students' awareness of task related progress (Edelson 2001). Research indicates that awareness support positively affected students' self-regulation and knowledge construction (Buder and Bodemer 2008). Computer-supported learning environments are able to log students' learning process, and employ these logs to increase students' group and task awareness. Within the present study, we focus on task awareness, and provide students with information considering their drawing activities and progress on the drawing task.

# **Research questions and hypotheses**

In the introduction, we described the potential benefits of collaborative drawing and illustrated how high quality (transactive and epistemic) interaction has the potential to increase students' collaborative knowledge construction. We also stressed that support often is needed to ensure that students engage in meaningful discourse. Scripting and awareness support were introduced as possible ways to scaffold students' collaborative drawing experience. Against this background two experimental conditions were developed in which students were either provided with awareness prompts or a collaboration script as part of their collaborative drawing task; students in the control condition worked with a basic version of the task without additional support. Furthermore, we investigated how the collaboration script and the awareness tool affected the transactive and epistemic quality of students' discourse. The quality of students' knowledge construction in terms of surface level conceptual knowledge as well as their deeper level understanding of the photosynthesis process. Based on the literature presented above; the following research questions and hypotheses are formulated:

R1. To what extent does the collaboration script support students' discourse quality? H1. Considering that the script stresses comparing, discussing and combining knowledge and ideas during the drawing activity, it is hypothesized that students in the scripted condition will demonstrate more transactive processes (part of the social modes dimension) than the students in the awareness and the control condition.

R2. To what extent do awareness prompts support students' discourse quality?

H2. Considering that the awareness tool aims at increasing students' awareness about the separate domain concepts and processes they included in their drawing, it was hypothesized that students in the awareness condition will engage in higher levels of the epistemic discourse than students in the scripted and the control condition.

R3. To what extent does the collaboration script support the quality of a group's final drawing?

H 3. Since students' focus on the script (i.e., comparing, discussing, and combining individual drawings) might disturb students' natural drawing process, it is hypothesized that drawing quality in the scripted condition is lower than in the awareness condition and the control condition.

R4. To what extent does awareness prompts support the quality of a group's final drawing?

H4. Considering that the awareness tool aims at increasing students' awareness about the concepts and processes they represented in their drawing, it was hypothesized that the awareness condition will result in the construction of higher quality drawings than the scripted condition and the control condition.

R5. To what extent does the script facilitate knowledge construction concerning the domain of photosynthesis?

H5. Considering that transactivity (which is fostered by the script) is associated with individual knowledge construction (Teasley 1997), it is hypothesized that the script will positively affect students' knowledge construction on low and deeper level conceptual understanding of the photosynthesis process.

R6. To what extent do awareness prompts facilitate knowledge construction concerning the domain of photosynthesis?

H6. We expect that students in the awareness condition demonstrate high scores on the low level conceptual understanding as the awareness tool aims to increase students' awareness concerning the separate concepts and processes they included in their drawing.

# Method

# Participants

Ninety-four fifth-grade students (47 dyads, aged 10–11), from three primary schools in the Netherlands, participated in this study. Schools were located in similar middle of the road neighborhoods. Participation was part of their regular classroom activities. Students were randomly paired within their own class and assigned to one of three conditions. The classroom teachers checked the combinations of students, to ensure that the paired students would get along with each other. Two dyads were removed, one from the control condition and one from the scripted condition, because they did not complete the entire session. The analyses have been conducted on 45 dyads: 12 dyads in the control condition, 17 dyads in the awareness condition, and 16 dyads in the scripted collaborative drawing. In the control condition we had six mixed gender dyads, three FF dyads, and three MM dyads. The awareness condition consisted of eight mixed gender dyads, two FF dyads, and seven MM dyads. The scripted condition consisted of five mixed gender dyads, five FF dyads, and six MM dyads.

# Domain

Students worked on a collaborative drawing task on photosynthesis, which is in parts standard curriculum content according to the guidelines for primary education (reflected as core objectives by the Ministry of Education; SLO 2009).

To get acquainted with this new topic, students in both conditions read a text on photosynthesis. This text was adapted from fifth grade instructional materials developed by SchoolTV (2010). The text covered the basic concepts and processes related to photosynthesis (e.g., substances involved in the photosynthesis process, exchange of carbon dioxide and oxygen between plants and animals/humans). Students' main task was to collaboratively create a drawing that was suitable to explain photosynthesis to other fifth grade students that were not familiar with photosynthesis. During the instruction, the experimenter stressed that the created drawing should be informative rather than aesthetically pleasing.

# Learning environment and conditions

Students worked with different versions of the same collaborative learning environment. Students in the awareness condition received domain-related prompts that were based on the characteristics of their drawings. Students in the scripted condition were invited to compare individually created drawings, elaborate on the observed difference between these drawings and subsequently make one shared drawing. Students in the control condition worked with a basic version of the task without additional support. In all conditions students' worked in dyads on separate tablet PCs with interactive penbased input devices. They used a shared digital drawing tool to create the drawing. Collaborating students were seated face-to-face behind their own tablet PC and were stimulated to negotiate about the drawing. For the study, existing Java-based drawing software has been modified and adapted to provide three different conditions. In all conditions, the software allowed the students to freely draw and delete strokes and shapes, and to create, edit, and delete text boxes (see Fig. 1).

To create a collaborative drawing platform, the computers were connected within a local wireless network. To provide students with shared workspaces, the software had been synchronized for the dyads with the help of the SQLSpaces communication framework (Giemza et al. 2007). The drawing tool automatically stored created drawings, and logged additional information about all user actions for detailed analyses and replays.

In the *control condition*, the participants were using the basic version of the software as described above. The dyads worked synchronously throughout the complete collaborative drawing phase. Five minutes before the end of this phase, the students were prompted to finish their drawing.

In the *awareness condition*, the software used group clustering and sketch-recognition algorithms (van Joolingen et al. 2010) to detect features of the drawings, and to prompt the students with information and hints (e.g., to draw the relevant objects from the text or to use arrows to indicate important processes). The software checked students' drawing at 5 min intervals for the amount of objects present in the drawing, the presence of specific objects



Fig. 1 Basic user interface of the drawing tool with awareness prompt

(like arrows) and the use of labels (see Fig. 1). For example, students that represented no or only a few objects, received a prompt with information about searching for relevant objects in the original text and stimulating the students to represent these objects in their drawing. In later stages of the collaborative drawing process prompts focused on the specification of the relations between concepts and the important processes in students' drawing. For example, students who used no arrows during the second half of the session received information about the use arrows and the identification of important processes.

In the *scripted condition* students worked on a sequence of activities starting with a 13 min individual drawing phase, after which the students could see their partners' drawing. During the 9 min selection phase, students were asked to agree on and select elements that would act as a basis for a joint drawing. They could identify elements from the drawing by circling them, and transport them to the joint drawing by clicking the circled drawing element. After selecting the elements for the joint drawing, students had 13 min to finalize the shared drawing. Five minutes before the end of this phase, the students were prompted to finish their drawing. Figure 2 shows a screenshot of the tool in the scripted condition. To the left, you see the individual drawings of both students, which are being combined to one shared drawing to the right.

### Data analysis

To gain understanding of the way that the supportive measures affected students' collaboration, we evaluated the effect of the experimental conditions on students' discourse, quality



Fig. 2 Drawing tool in scripted condition

of their final drawing, and their test-scores. First, we evaluated the impact of our interventions on the epistemic and transactive quality of the discourse. Since effective collaboration may not systematically produce higher learning gains, we used students' final drawing as an indicator of group performance, and the learning gains on a concept recognition test and an open recall test as an indicator of students' individual knowledge construction. A detailed description of the dependent variables is provided in the following sections.

### Discourse analysis

Students' discourse was used as a data source that provided us with information about students' collaborative interaction and their collaborative knowledge building process within each of the three conditions. A combination of a qualitative and a more quantitative approach was used to explain the differences between conditions. For the qualitative analyses, excerpts from students' dialogues will be presented to provide examples of how students collaborated and worked with the tools that were available in the three different version of the learning environment.

To assess the quality of students' discourse, a coding scheme based on the work of Weinberger and Fischer (2006) was developed. Discourse was coded in terms of the epistemic and transactive quality of the conversation. Students' interaction was transcribed and segmented into utterances. An utterance was defined as a series of words that has a single communicative function; it is a distinct message from one student to another student (a speaking turn with one communicative function, speaking turns that consisted of more communicative functions were split). Second, we distinguished between on- and off-task activities. On-task communication refers to activities that are aimed at completing the task. Third, each on-task utterance was coded with respect to both, the transactive and the epistemic quality.

Transactivity describes how students respond to the contributions of their collaboration partner. Based on the framework presented by Weinberger and Fischer (2006), we distinguished five types of utterances representing different degrees of transactivity, externalization, elicitation, quick consensus building, integration-oriented consensus building, and conflict-oriented consensus building. Externalization refers to utterances in which students articulate ideas to the group without referring to their partners. During *elicitation* students question their partner to receive additional information. Externalization and elicitation primarily serve the exchange of information. Quick consensus building occurs when students simply agree or disagree with the ideas their partner contributed, without further elaboration or critiquing. Integration-oriented consensus building is characterized by building on the ideas of a partner, integration of multiple ideas or viewpoints, or taking over the perspective of a partner. Conflict-oriented consensus building occurs when students operate on their partners reasoning by critiquing and modifying their contributions or presenting them with alternatives. Integration-oriented consensus building and conflict-oriented consensus building are considered transactive processes. An overview of transactive coding including examples of utterances in each category is provided in Table 1.

On the epistemic dimension, on-task communication was coded in terms of coordinative talk (non-epistemic talk) and content-related talk. For an overview of epistemic coding, see Table 2. Utterances related to coordination, planning, and monitoring of the learning process was coded as coordinative talk. Utterances that related to the content of the learning task were coded as content-related talk. Content-related talk was coded into four categories. We distinguished the following levels of content-related talk. Concept naming, referring to utterances in which students named a concept or used a concept without defining it or relating it to other concepts or processes. Concept definition refers to utterances with which students attempted to describe the meaning of a concept. Process definition refers to utterances with which students attempted to describe the meaning of a concept.

Table 1 Ov	erview of	transactive	coding
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Categories	Examples from students' interaction
Informative talk	
Externalization	'We should draw a plant.'
Elicitation	'Is it okay for me to draw the roots?'
Quick consensus building	
Agreeing	'Okay.'
Disagreeing	'No.'
Transactive talk	
Integrating	I see what you mean.'
Elaborate critiques and modification	'Okay, but isn't it like that?'
Off-task talk	
Off-task talk: neutral	'I have to go to the gym later.'
Off-task talk: conflict	'Stop being so mean and annoying!'

to describe a process. Concept-process connection refers to utterances with which students described the connection between concepts and processes.

To assess the inter-rater reliability of the coding procedure, a second coder coded three protocols, consisting of 401 spoken segments. The inter-rater reliability coefficient for coding the social dimension was .82 (Krippendorff's alpha). The inter-rater reliability coefficient for codes on the epistemic dimension was .86 (Krippendorff's alpha). Percentagewise scores were calculated for each sub-category of both dimensions. These scores indicate the proportional amount of utterances made in a certain category.

# Drawing quality

To code the content of the drawings, a coding scheme was developed that focused on the presence of different concepts, properties, and processes that define photosynthesis. The presence of a 'flower' was coded as the concept vegetation. The use of an arrow to indicate 'the absorption of water and minerals from the ground' was coded as the representation of a

Table 2         Overview of epistemic code	ding
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Categories Examples from students' inte	
Content talk	
Concept naming	'It's a plant.'
Concept definition	'Carbon oxide is what we breathe.'
Process definition	'It travels from stalk to leaves.'
Concept-process connection	'The roots extract water.'
Coordinative talk	
Coordination	'Let's draw oxygen as little dots.'
Off-task talk	
Off-task talk: neutral	'I have to go to the gym later.'
Off-task talk: conflict	'Stop being so mean and annoying!'

process. The representation of 'Sugar as a plants' own nutrition' and a representation of 'oxygen as a waste product' were coded as representations of properties. A second rater coded about 20 % of the drawings to assess inter-rater reliability; Krippendorff's alpha reached .96 in total. The overall drawing quality was calculated as the sum score for the number of drawn concepts and processes and annotated concepts and processes.

### Individual knowledge construction

To assess students' knowledge construction on photosynthesis two tests were used: a concept recognition test and an open recall test. The concept recognition test focused on students' conceptual knowledge, while the open recall test assessed students' structural knowledge of processes and relations in the domain. Both tests were judged by two elementary school teachers, to ensure that they were comprehensible for the students. Since the students were expected to enter the study with minimal prior knowledge on the processes of photosynthesis, the open recall test was administered after the students got the opportunity to study a text on photosynthesis. Students' conceptual prior knowledge was assessed by means of the concept recognition test; prior knowledge was measured before the learning session.

The concept recognition test aimed at assessing students' conceptual knowledge about photosynthesis. The test consisted of a list of 36 words, from which 13 were related to the photosynthesis process. Students were asked to circle the related items. The concept recognition test was administered three times during the experimental session: before the learning session, after the students studied the text on photosynthesis, and after the collaborative drawing session. Cronbach's alpha ranged from .544 to .845. A possible explanation for the relatively low Cronbach's alpha is that the domain was new for the students and their prior knowledge was low and therefore some of the students might have been guessing on the pretest.

The open recall test consisted of six questions that asked students to describe and explain specific aspects of the photosynthesis process, like the gas exchange. After students studied the introduction text on photosynthesis, they completed the first open recall test. The second open recall text was completed after the collaborative drawing session. Both versions of the open recall test were identical. An elementary school teacher assisted in the construction of an answer key for the open recall test. Students' answers were checked against this answer key and points were allocated for each answer. Approximately 20 % of the data was coded by a second rater. Inter-rater agreement (Cohen's Kappa) between the two coders reached .82.

For each test, learning gains were calculated. Conceptual learning gain was assessed after studying the text on photosynthesis (intermediate test minus pretest scores), and after studying and processing the text on photosynthesis in the collaborative drawing session to gain insight in the added value of the collaborative drawing activity (posttest scores minus intermediate test scores)

# Procedure

The experiment consisted of several phases: an introduction and training phase (35 min), and a collaborative drawing and testing phase. The experiment took place at a regular school day. A 20-min-break was scheduled between the introduction and training phase and the collaborative drawing phase. Students were seated in dyads and worked on two separate and penbased input screens. All students followed the same sequence of events.

# Introduction and training

The introduction and training session was primarily meant to prepare students for the actual experiment. During the introduction and training session, students worked individually. The entire introduction and training session lasted 35 min.

*Introduction (5 min)* The session started with a short introduction to the experiment in which the experimenter explained the outline of the experiment and the different tests students had to complete.

*Training (15 min)* Students received a short training in how to make a drawing based on an informative text. Students were asked to read a text on the water cycle. When all students finished reading, the experimenter demonstrated the drawing software. Together with the students the experimenter located the main concepts and relations in the text and visualized them by drawing, simultaneously explaining what was drawn and why it was drawn.

*Practice (15 min)* After the training, students practiced individually with the software. They were asked to create their own individual drawing of the water cycle. During this phase the researchers checked whether students were able to make a drawing from text and operate the drawing software. Students were free to ask questions about the drawing procedure as well as the software.

# Experimental session

After a 20-min-break the experimental session started. In this session students completed several knowledge tests, studied a text on photosynthesis and worked collaboratively in one of the three conditions. The duration of the entire experimental session was 75 min.

*First concept recognition test (5 min)* The experiment started with a concept recognition test. The experimenter explained the format of the test. Since photosynthesis is a rather new topic for the students, the experimenter stressed that this first test was meant to measure students' prior knowledge of photosynthesis.

*Introduction to photosynthesis (15 min)* Students received a text on photosynthesis. They were instructed to read the text carefully and think about concepts and processes they wanted to represent in their drawing.

Second concept recognition test and first open recall test (10 min) Students completed another concept recognition test and a first open recall test after they read the text on photosynthesis.

*Collaborative drawing phase (35 min)* Differences between conditions (control condition, awareness condition and scripted condition) became apparent in the collaborative drawing phase. Students in the control condition worked with the basic version of the drawing software. Students in the awareness condition worked with a version of the software that provided them with prompts that were based on the characteristics of their drawing. Students in the scripted condition worked according to the script that started with a 13 min individual drawing phase.

*Third concept recognition rest and second open recall test (10 min)* Student completed the last concept recognition test and open recall test.

### Results

In this section we combine qualitative analysis of students' discourse and their interactions with the learning environment with quantitative data to fully explain the differences between conditions. To gain a deeper understanding of the collaborative learning processes in both conditions, we will first discuss six representative excerpts, providing examples of students' interaction and their interaction with the learning environment and the provided tools. Second, we present the results of the multivariate analyses performed on the coded process data and test scores. Finally, we report the relation between test-scores and the type and amount of inquiry learning and consensus building activities in student interaction.

### Case analyses

In this section, we take a closer look at students' interaction in the three conditions to provide examples of how students worked with the tools that were provided in the three versions of the learning environment. Our analysis focuses on the collaborative drawing process and the consensus building activities students engaged in during their interaction with the learning environment. The presented excerpts provide examples of the collaborative drawing process and the interaction modes presented in Tables 1 and 2. More specifically, the case studies reveal how the support available in both conditions affected students' inquiry learning process as well as their interaction. To gain insight into how dyads worked in the different conditions, we selected two example excerpts from each condition (translated from Dutch).

### Control condition

Students in the control condition were instructed to create a joint drawing based on a text on the photosynthesis process. Students were not supported with a script and received no additional cues from the drawing tool. Control students' dialogue merely focused on the construction of their drawing. They often engaged in quick-consensus building activities.

Table 3 shows a typical example of a dyad in the control condition. In this example Fred and Audrey are working on their shared drawing and talking about different aspects of their drawing

Fred and Audrey not really refer to their partner's utterances. Fred indicates they need a cloud (turn 1). Audrey does not really respond to Fred's cloud suggestion by telling him they need stomata. And Fred does not refer to the content of her utterance when he talks about breath and air in (turn 3 and 4). In their conversation, Fred and Audrey name concepts without really discussing their relationship with other concepts. Audrey keeps stressing they need stomata and Fred seems to be focused on the cloud (turn 8). Audrey and Fred do not use domain related arguments to try to convince each other that they need stomata (turn 5). Her utterances are not related to Fred's utterances about air and breath. Fred responds by indicating that they also need carbon dioxide in their drawing (turn 6), suggesting that Fred is focusing on the gas-exchange. Audrey tells Fred that she will draw holes in the leaves (turn 7).

Another typical example of a dyad in the control condition is presented in Table 4. The excerpts start with a short discussion about raindrops (turns 1 and 2). Heather is not sure about the way Anne represents raindrops (turn 3). Anne and Heather engage in quick consensus

communication between Fred and	Turn	Student	Message
Audrey (excerpt 1)	1	Fred	We still need a cloud.
	2	Audrey	We need stomata.
	3	Fred	I draw a breathing person.
	4	Fred	This person breaths fresh air.
	5	Audrey	We need stomata.
	6	Fred	We also need carbon dioxide.
	7	Audrey	I will draw holes in the leaves for the stomata.
	8	Fred	Okay.
	9	Fred	So this is the cloud, with CO2.

building (turns 4, 5, 6 and 7) about the representation of the raindrops. In turn 9 Anne suggests they should start working on the roots. Heather tries to explain that they should also include stomata (turn 10). But when Anne is unsupportive (turn 11) and makes fun of the dots, she quickly agrees to move to something else (turn 12). Heather indicates that she thinks that drawing the water transportation through the roots is not important (turn 13). Without further questioning Anne agrees and asks what their next action should be (turn 15). Heather and Anne also name a number of concepts without further explaining them or relating them to other concepts. In their discussion they are not building on each other's ideas and move rather quickly from one concept to the next.

With respect to the epistemic quality of the discourse students in both excerpts externalize domain-related concepts (like stomata, carbon dioxide, green plants, etc.).

Students in the first excerpt (Table 3) seem to be working next to each other instead of together, and the students in the second excerpt (Table 4) are focused on continuation of the

Turn	Student	Message
1	Heather	Why don't you make raindrops?
2	Anne	That is what I am doing.
3	Heather	Those things are not raindrops.
4	Anne	I like to draw them like this.
5	Heather	Okay.
6	Heather	The plant thing is not finished, we need to draw the green things (referring to chloroplasts)
7	Anne	Hmm, okay.
8	Anne	So these dots are supposed to be the green things.
9	Anne	Now we should work on the water and the roots
10	Heather	No, we need to draw these other dots, stomata.
11	Anne	They have all the dots they need, dot here, dot there, dotties everywhere, dot.
12	Heather	Okay, let's move on.
13	Anne	Now, the roots and the water going up.
14	Heather	It's not important.
15	Anne	Okay, what is next.

 Table 4
 Sample episode from the communication between Heather and Anne (excerpt 2)

process and use quick consensus building to overcome disagreement. Hence, the transactivity of the discourse is low.

### Awareness condition

Students in the awareness condition were supported with awareness prompts that were based on their intermediate drawing quality. In the excerpts presented in Tables 5 and 6 we present two typical reactions to awareness prompts. The examples illustrate that the awareness prompts often stimulated students' to ask their partner for additional information or to look for specific information (for example concepts) in the text and re-read parts of the text. The examples suggest that during this process students respond to their partners' ideas, which might result in higher levels of transactivity.

Table 5 shows a conversation between Mandy and Peter, a dyad within the awareness condition. Mandy and Peter just received a prompt. In turn 1, Mandy rephrased the prompt. Peter responded by stressing that they should draw processes (turn 2). Peter looked for processes in the original text (turn 5), and Mandy also consulted the text to check whether they included all the important concepts in their drawing (turns 8 and 9). The excerpt illustrates that students did not necessarily respond by including arrows in their drawing. It seemed that the prompt stimulated Peter and Mandy to inspect the text and re-read parts of text (see also turns 10 and 11). After re-reading the text, Mandy and Peter work with what they read, stressing that oxygen is important for human life and that carbon dioxide is important for plants. After stating this Peter returns to the text (turn 15).

In Table 6 the conversation between Nathaly and Marei is presented. Both students listen to each other's suggestions and build on them. Nathaly and Marei are in the process of drawing a doll (turn 1 and 2). Marei and Nathaly exchange suggestions, ask questions and answer them (turn 3, 4 and 5). Then they notice a wait sign on the screen (turn 6). The wait sign is followed by the prompt that is rephrased by Nathaly in turn 8. Marei continues to talk about the oxygen

Turn	Student	Message
1.	Mandy	Read this, we are supposed to do processes with arrows.
2.	Peter	Processes, processes.
3.	Mandy	Hmmm
4.	Mandy	Sunflower, roots of the sunflower.
5.	Peter	Sugar is a nutrient for the plant (reads from text).
6.	Mandy	What are you doing?
7.	Peter	Drawing sugar lumps, what did you think?
8.	Mandy	Roots, the plant uses roots, stems, and the leaves (listing items from the text).
9.	Mandy	Check, check, we have them.
10.	Peter	Oxygen is released as a side product (reads from text).
11.	Peter	Oxygen is released, released as a side product (repeats).
12.	Mandy	Don't draw it so small.
13.	Mandy	Oxygen is important for human beings, we die without oxygen.
14.	Peter	Hi hi, and carbon dioxide is important for plants, they use it to make the oxygen
15.	Peter	Chloroplasts are important tools that a plant uses for the production of oxygen and sugar (reads from text).

 Table 5
 Sample episode from the communication between Mandy and Peter (excerpt 3)

Turn	Student	Message
1.	Nathaly	It does not matter if you can't draw it beautiful
2.	Marei	I know, but this doll needs at least two arms.
3.	Marei	His mouth should be open so that he can breathe.
4.	Nathaly	He is breathing because of the tree, it's producing oxygen.
5.	Marei	Yes, yes we should draw that.
6.	Nathaly	There is a wait sign on my screen.
7.	Marei	Mmmmm.
8.	Nathaly	We have to finish our drawing and check if we have all the important things (rephrasing a prompt),
9.	Marei	We still should do the arrow for the oxygen.
10.	Nathaly	We should do the water it starts with the water.
11.	Marei	Not just the water, also the sun and lots of other things.
12.	Nathaly	Yes, yes, the entire list (giggles) with the sunbeams.
13.	Marei	Plants usually take the water that they need from the soil, with their roots (reads from text).
14.	Nathaly	I know, I know.
15.	Nathaly	Okay we have the soil, good for us.
16.	Marei	Ha ha, there is even an earthworm in it.
17.	Marei	Carbon dioxide is in the air, it enters the leaves through little holes called stomata (reads from text).

Table 6 Sample episode from the communication between Nathaly and Peter (excerpt 4)

(turn 9), and Nathaly comes up with another suggestion (turn 10). Their conversation changes a bit after the prompt. Both students add concepts to the list (turns 11 and 12), and Marei seems pretty focused on the text. Marei starts reading about the water absorption process (turn 14), and Nathaly indicates that she already is familiar with this (turn 15) and that they already included the soil in their drawing (turn 16). After their short conversation Marei continues to read from the text (turn 18).

The presented excerpts from the awareness condition illustrate that students typically responded to the prompts by studying and reading out loud the original textual resource. They searched the text for concepts and processes and talked about including these concepts in their drawing. However, not all students have actually included these concepts in their joint drawing. The excerpt presented in Tables 4 and 5 suggest that students may have discussed different concepts that they could include in their drawing until another prompt appeared, and they again started searching the original text for clues concepts and processes for example when Nathaly (excerpt 2, turn 4) explains that their doll figure is breathing because the tree produces oxygen. In contrast to the students in the control condition, the students in the awareness condition are more responsive to their partners' suggestions. The level of transactivity seems higher in the excerpts from the awareness condition.

#### Script condition

In the excerpts presented in Tables 7 and 8, we illustrate how students in the scripted condition combined their individual drawings into one shared representation.

Turn	Student	Message
1.	Carla	So let's take your plant.
2.	Wendy	With the roots, we need them for the water.
3.	Wendy	Take the roots.
4.	Carla	See, I took them.
5.	Wendy	Okay, that should be it.
6.	Carla	Ready.
7.	Wendy	Okay, this is it We have to finish.
8.	Wendy	Hihi, your human is so funny.
9.	Carla	We have to do oxygen, it's all about oxygen.
10.	Wendy	How can we make clear that oxygen is in the air?
11.	Carla	We can take the human doll and the oxygen will go to the human from the plants.
12.	Wendy	Yes, yes.
13.	Wendy	And I will draw an arrow over here and it will go to the doll.
14.	Carla	So here is the doll.
15.	Carla	What are you doing?
16.	Wendy	I am drawing little oxygen dots.
17.	Wendy	What are you doing?
18.	Carla	I am helping you with the oxygen.
19.	Wendy	You can finish the plant, with the little holes for the oxygen.
20.	Carla	Okay.

 Table 7 Sample episode from the communication between Carla and Wendy (excerpt 5)

In excerpt 5 (see Table 7) the conversation between Carla and Wendy is presented. Carla and Wendy are in the process of creating a shared drawing based on their individual

 Table 8 Sample episode from the communication between Abdel and Claudia (excerpt 6)

Turn	Student	Message
1.	Abdel	These flower come straight out of the soil, something is missing.
2.	Claudia	Yes, leafs, and they are important.
3.	Abdel	And leafs.
4.	Abdel	We have to take all pieces of this plant over there.
5.	Claudia	Hmm, we can leave the shadow
6.	Abdel	So this is it, I guess, for the plants.
7.	Claudia	If we need more we can always draw it.
8.	Abdel	We have a lot of plants and trees, it's an entire garden.
9.	Abdel	Hmm, what is this leaf doing over there?
10.	Claudia	It's a larger leaf to show all the leaf things.
11.	Abdel	Are those things holes for the oxygen?
12.	Claudia	Yes, and for that other stuff, and those are the green spots that actually make the oxygen.
13.	Abdel	Huh, okay I see you drew them in a different way.
14.	Abdel	Nice, nice.
15.	Claudia	Yes, we can write here that this is inside all of the leaves.
16.	Abdel	And here is the air with the oxygen in it.

drawings. Carla started with suggesting that they should take Wendy's drawing of a plant (turn 1). Wendy stressed that the roots should also be included in the shared drawing, because the plant needs them for water (turn 2). Turns 3 to 6 refer to the coordination of copying and pasting elements form the individual drawing to the shared drawing. Wendy stressed that they had to finish (turn 7). In the finalization phase, Carla suggested that they should include oxygen; because this is one of the key concepts in the photosynthesis process (turn 10). Like students in other conditions (see Table 10), they found it difficult to indicate that oxygen is in the air (turn 10). Carla suggested that they should make clear that oxygen is something that goes from the plant to the human (turn 11). Wendy thought this was a good suggestion (turn 12) and she suggested using an arrow (turn 13) to indicate this process. Later (turn 16), Wendy drew dots to complete the representation of oxygen. Carla responded positively by helping her (turn 18), and Wendy suggested that to improve the drawing by including little holes for the oxygen (turn 19, probably referring to stomata).

Abdel and Claudia are also discussing which elements they want to include in their final drawing (see Table 8). In the first utterance Abdel notices that something is missing. Due to a mistake the students made while they were copying the plant, they did not include the stem and leafs. Claudia (turn 2), stresses that the leaves are important. Abdel and Claudia continue their discussion about what to take (turns 4 to 8). They talk about what is important (turn 5) and how many plants and tree should be included (turns 6 and 8). Abdel is not sure about the larger leaf in Claudia's drawing (turn 9). Claudia explains that this is a kind of close up of a leaf in which she highlighted smaller elements, she refers to the smaller elements as "the leaf things" (turn 10). Abdel asks more clarification questions (turn 11) and Claudia explains (turn 12). In turns 13 and 14 Abdel expresses that he likes the way Claudia represented the leaf. Claudia (turn 15) suggests they could indicate that these elements are present inside all leafs.

A typical pattern in the scripted condition is that during the collaborative phase students explored elements from their individual drawing and when needed asked for explanations. In contrast to students in the awareness condition who referred to the original text in their dialogues, students in the script condition refer to each other's individual drawings. The excerpts illustrate that taking elements from the individual drawing requires a certain amount of coordination. In the excerpt of Carla and Wendy (Table 7), we see that Carla and Wendy inform each other about their actions and are aware of the time constraints. Abdel and Claudia (Table 8) need to coordinate themselves on top of the external regulation provided by the script; they discuss the amount of plants and trees that have to be included in the final drawing. The excerpt presenting Abdel's and Claudia's communication also illustrates that Abdel and Claudia are trying to understand the drawing elements from their partners individual drawings before including it in the final drawing.

### Synopsis

The excerpts from students' conversation during the collaborative drawing task show how students' collaborative actions are affected by the support they received. It becomes clear that students in the awareness condition in reaction to a prompt often inspected the original text. When they were prompted to indicate processes by drawing, students did not necessarily respond by including arrows to indicate processes. They responded by looking in the text for examples of processes, but often ended up listing and checking concepts that could be represented in their drawings and reading them out loud to each other. Students in the scripted condition were invited to compare their drawings and make a selection of items that they would like to include in their shared drawing. They were referring more to the knowledge and drawing of their collaboration partner. The presented excerpts suggest that students in both experimental

conditions were more responsive to the utterances made by their partner. They also illustrate that in the scripted condition the combination of drawing elements from two individual drawings posed additional needs to coordinate.

### Dialogue acts

Students' discourse was recorded, transcribed, and coded using the coding scheme presented in the "Method" section. For dyads in the scripted condition, the time they actually collaborated with their learning partner was shorter and they produced fewer utterances than unscripted students. Percentagewise scores were used to rule out an effect of difference between conditions in amount of utterances.

# Transactivity of the conversation

Table 9 gives the average percentages of utterances in the epistemic categories for each condition. The result of a MANOVA with the percentages of transactive processes as the dependent variables revealed significant differences between conditions, F(18, 68) = 3.28. p=.000, Wilks Lambda = .29,  $\eta^2=.44$ . Subsequent univariate analyses revealed significant differences between conditions regarding the percentage of elicitation related utterances, F (2, 42) = 4.694, p=.0014, Cohen's d=1.01, the percentage quick consensus building utterances that aimed at reaching agreement, F (2, 42) = 5,186, p=.009, Cohen's d=1.05, and the percentage of quick consensus building utterances that revealed disagreement between students within a dyad, F (2, 42) = 4.326, p=.019, Cohen's d=0.94. Post-hoc Bonferroni corrected comparisons revealed that the percentage of elicitation related utterances is higher in both experimental conditions than in the control condition. All post hoc analyses using the Bonferroni procedure used adjusted alpha levels of .016 per test (.05/3). No significant differences were found between the two experimental conditions. The percentage of utterances that is related to quick consensus building activities (both agreement and disagreement oriented) is higher in the control condition than in both experimental conditions. The experimental conditions did not differ in the percentage of quick consensus building activities.

Percentages	Control		Awareness		Script	
	М	SD	М	SD	М	SD
Externalisation	33.63	6.42	32.21	4.43	32.20	5.11
Elicitation <sup>a</sup>	16.99	3.57	21.40	4.34	21.77	5.47
Quick consensus: agree <sup>a</sup>	13.18	3.58	10.16	2.53	9.86	2.94
Quick consensus: disagree <sup>a</sup>	3.51	2.53	1.56	1.16	2.00	1.79
Transactive: integration <sup>a</sup>	1.84	1.16	4.16	2.12	5.44	2.49
Transactive: critical <sup>a</sup>	.97	1.07	3.48	1.92	1.89	1.47
Off task: neutral	19.39	4.80	20.36	5.74	20.12	12.55
Off task: conflict	2.69	3.04	1.10	1.10	0.60	.81
Paraverbal utterance	7.87	2.76	5.57	3.33	6.12	3.14

 Table 9 Percentagewise scores and standard deviations for dyads regarding transactivity

<sup>a</sup> Control differed significantly from the awareness and script condition

We also found differences between conditions with respect to transactive talk like integration, F (2, 42) = 9,961, p=.000, Cohen's d=1.36, and critical consensus building, F (2, 42) = 9.936, p=.000, Cohen's d=1.12. Post-hoc Bonferroni corrected comparisons revealed that the percentage of integration-related messages and critical consensus building activities was higher in the experimental conditions than in the control condition.

# Epistemic processes

Table 10 gives the average percentages of utterances in the epistemic categories for each condition. The results of a MANOVA revealed significant differences in epistemic processes, F (16, 70) = 3.82. p=.000, Wilks Lambda = .29,  $\eta^2$ =.466 between conditions. Subsequent univariate analyses revealed that significant differences were found between the percentage naming of domain-related (medium size effect) concepts, F (2, 42) = 7.470, p=.017, Cohen's d=0.61, and substantial differences were found between the percentage of domain related concepts, F (2,42) = 4.072, p=.024, Cohen's d=.99, and processes, F (2,42) =6.127, p=.005, Cohen's d=0.85, that were defined. Furthermore, a medium size effect of condition was found for the percentage of coordination related utterances, F (2,42) = 4.476, p=.017, Cohen's d=0.60 that were exchanged within dyads. Post-hoc Bonferroni corrected comparisons indicated that students in the control and awareness conditions named more concepts than their peers in the scripted condition. Furthermore, students in the awareness condition and scripted condition defined a higher percentage of domain related concepts than their peers in the control condition. With respect to the percentage of domain related processes that were defined, post-hoc Bonferroni corrected comparisons revealed that students in the scripted condition exchanged a higher percentage of process definitions than their peers in the control condition. No differences between the other conditions was found regarding the percentage of process definitions exchanged during the learning session. Post-hoc Bonferroni corrected comparisons revealed that students in the script condition exchanged a higher percentage of coordinative utterances than their peers in the control condition.

	Control		Awareness		Script	
	М	SD	М	SD	М	SD
Concept naming <sup>a</sup>	39.10	5.09	39.02	5.12	32.52	5.78
Concept definition <sup>b</sup>	.43	.66	1.63	1.29	1.91	1.98
Process definition <sup>c</sup>	.03	.12	.32	.41	0.48	.53
Concept-process connection	2.71	1.76	2.83	2.33	3.33	1.28
Coordination <sup>a</sup>	27.85	4.59	29.18	6.33	34.92	6.07
Off task: neutral	19.39	4.80	20.36	5.74	20,12	12.55
Off task: conflict	2.61	3.04	1.10	1.10	0.60	.81
Paraverbal utterance	7.87	2.76	5.57	3.33	6.12	3.14

Table 10 Percentagewise scores the dyads on the epistemic dimension of the coding scheme

<sup>a</sup> Control and awareness condition differed significantly from the script condition

<sup>b</sup> Control condition differed significantly from awareness condition

<sup>c</sup> Control condition differed significantly from script condition

Drawing quality

Table 11 provides the average drawing quality scores for each condition. An ANOVA on the overall quality of the drawing (composed of the sub scores) revealed a significant, medium-size effect of condition on drawing quality, F(2, 42) = 5.31, p=.009, Cohen's d=0.52. To gain insight into the way that students in the different conditions constructed their drawing, a MANOVA with the number of represented concepts, the number of annotated concepts, the number of represented processes and the number of annotated processes as dependent variables and the conditions as the independent variable was performed. The MANOVA revealed no significant differences in the number of concepts represented in the drawing, F(2, 42) = 1.29, p=.28, but a medium significant difference between conditions was found for the number of annotated concepts, F(2, 42) = 5.229, p=.009, Cohen's d=0.68. A Bonferroni corrected post-hoc comparison of the means revealed a significant difference between the awareness condition and the scripted condition in favor of the scripted condition. All post hoc analyses using the Bonferroni procedure used adjusted alpha levels of .016 per test (.05/3). No significant differences between the other conditions were found. No significant differences between conditions was found for the number of processes represented in the drawing, F(2, 42) = 3.00, p=.061, and the number of processes annotated in the drawing, F(2, 42) = 2.78, p=.073.

Students were randomly assigned to three conditions, so no significant differences on students' prior knowledge between conditions was expected. Analysis of variance on students' pretest scores supported this expectation by revealing no initial differences between conditions on the concept recognition test and the first open recall test administered. Table 12 provides an overview of the mean scores on the concept recognition test and open recall test for the three conditions.

A univariate analysis of variance revealed no significant effect of condition on the learning gain from pretest to intermediate concept recognition test, F(2,87) = .110, *n.s.* However, a significant, medium size effect of condition on the learning gain from intermediate test to posttest, F(2,87) = 5.533, p=.005, Cohen's d=0.56. A post-hoc Bonferroni corrected comparison of the means showed a significant difference between the control condition and the scripted condition in favor of the scripted condition.

For the open recall test results, an ANOVA revealed a significant and medium size effect of condition, F(2, 87) = 5.449, p=.006, Cohen's d=0.56. A post-hoc comparison of the means using the Bonferroni procedure indicated that students in both experimental conditions outperformed their peers in the control condition. No significant differences were found between the awareness condition and the scripted condition.

	Control		Awareness		Script			
	М	SD	М	SD	М	SD		
Overall quality	13.31	6.55	10.19	3.69	16.06	4.99		
Concepts drawn	7.84	2.15	7.31	1.40	8.37	2.03		
Concepts annotated <sup>a</sup>	3.46	1.27	2.31	2.06	5.19	2.56		
Processes drawn	.85	1.07	.25	.58	1.12	1.31		
Processes annotated	1.15	1.77	.31	.60	1.38	1.45		

Table 11 Mean scores and standard deviations for drawing quality

<sup>a</sup> Awareness condition differed significantly from the control condition

Condition	Ν	Concept rec	cognition test	Open recall test		
		Pre-test	Inter-mediate	Post-test	Pre-test	Posttest
Control						
М	24	4.71	8.91	10.67	7.63	9.29
SD		3.24	1.71	1.27	2.12	1.92
Awareness						
М	34	4.56	9.15	11.65	7.53	10.67
SD		3.37	2.19	1.54	2.23	2.82
Scripted						
М	32	4.03	8.39	11.79	7.06	10.15
SD		3.16	2.46	1.22	1.65	1.64
Total						
М	90	4.41	8.81	11.43	7.38	10.01
SD		3.24	2.19	1.43	2.00	2.26

Table 12 Mean scores and standard deviations on the knowledge tests

Discourse and learning gains

Regression analysis was performed to gain insight into the relation between students' discourse and the learning and performance gains on both tests. First, we performed a stepwise regression analysis with the learning gains on the concept recognition test as a dependent variable, and the percentages students' communicated in the different discourse categories as independent variables. None of the independent variables was a significant predictor of students learning gains on the concept recognition test. A subsequent step-wise regression analysis on the learning gains on the open recall test as a dependent variable and the percentages students' communicated in the different discourse categories as independent's communicated in the different discourse categories as independent variables resulted in a significant model (see Table 13). The percentages talk on integration-oriented consensus building, concept definition and critical consensus building provided significant contribution to the prediction. With respect to the performance gains, none of the independent variables was a significant predictor of the quality of the shared drawing.

	Model 1 β	Model 2 β	Model 3 β
Intergration oriented consensus building	.54*	.49*	.43*
Concept definition		.27*	.25*
Critical consensus building			.19*
R <sup>2</sup>	.54	.60	.63
R <sup>2 Change</sup> (df)		.06 (89)**	.03 (89)*

Table 13 Results of regression analyses on learning gain on the essay test

\**p*<.05

#### Discussion

Studies by Van Meter (2001) and van Meter et al. (2006) demonstrated that supportive measures enhanced students' learning outcomes in individual drawing settings. The aim of the present study was to investigate to what extent awareness prompts and scripts supported students' learning outcomes and discourse in a collaborative drawing setting. A key finding of the present study is that awareness prompts as well as scripts resulted in higher levels of transactivity in students' dialogues. This finding was only partly consistent with our expectations. We expected the script to positively affect the transactivity of the dialogues, resulting in higher learning outcomes. We also expected that the awareness prompts would mainly influence the domain-related content of students' discourse and therefore positively affect the epistemic quality of the dialogue, resulting in higher quality drawings. In contrast to our expectations, the prompts did not have a positive effect on the number of concepts and processes students represented in their drawings. However, it positively affected the percentage of concepts students' defined during their dialogue.

With respect to the knowledge tests we found that students in both experimental conditions outperformed their peers on the concept recognition test and the open recall test. Contrary to our expectations no significant differences on the knowledge test were found between the two experimental conditions. The results of a regression analyses confirmed our expectation that the transactivity of students' dialogue was positively related to learning outcomes on the open recall test. This is in line with prior research (Teasley 1997). However, similar results were not found for the learning gains on the concept recognition test. The concept recognition test does not require the students to explain (parts of) the photosynthesis process like the open recall test. It could be that transactive communication is related to the construction of more complex and deeper knowledge than is assessed by the open recall question.

Examination of students' interaction provides possible explanations for our findings. The prompts as well as the different phases of the script might have regulated students' collaborative learning activities. The presented excerpts show that when students received awareness prompts (for example try to indicate processes by using arrows), students often consulted the text for information about processes and discussed the text with their partner. One can therefore argue that the awareness prompts also structured students' collaborative knowledge construction process and also increased their shared task focus. This shared focus made it easier for students to understand and articulate a response to the contributions of their partner, resulting in highly transactive discussions about domain related concepts and relations between these concepts. The highly transactive discussions might have positively affected students' learning, but did not necessarily result in higher quality drawings. The shared focus of students in the awareness condition was often directed to the textual resources. For these students it takes an additional step to actually represent these concept processes in the drawing. In contrast to the students in the awareness condition, students in the scripted condition typically focused on the individual drawings as a resource for their collaborative drawing. Students' attention in the scripted condition was already on the drawing and the screen, which might make it easier for them to directly represent the discussed concepts in the shared drawing. Students in the scripted condition annotated more concepts than their peers in the awareness condition. It is possible that the structure provided by the script induced students awareness about the tasks, the knowledge construction processes, and their shared responsibility for the final product. In the scripted condition some students noticed that their drawing might be completely clear to them, but is not necessarily clear to their collaboration partner. The excerpts revealed that when students' combine their individual drawings they often feel the need to provide additional explanations considering the meaning of the represented objects. Following the introduction, students switched between the text, their (upcoming) drawings and discussions with their collaboration partner. Coordination of the combination of activities might be complex for elementary school students. We tried to reduce the complexity by giving students a training in how to make a drawing based on an informative text. However, it might be interesting to asses students' flow and mood (Vollmeyer and Rheinberg 2006) during different phases of the learning task to gain insight into students' emotional state at a specific moment during the task.

All students, participating in the present study, received training in how to make a drawing based on an informative test. The example and structure provided in the training might have affected students' collaborative drawing process by helping them to focus on the representation of domain related concepts and relations. Excerpts from the present study reveal that students discussed the aesthetics of their drawings but mainly focused on the representation of domain related information. An interesting direction for future research would be to investigate how students react to objects and representations that are created by their collaboration partner, in more detail.

In the introduction we explain that the structure, provided by a script, alleviates students' need for coordinating activities (Weinberger et al. 2010). A surprising finding is that, in the present study, students in the scripted condition engaged in more coordinative processes than their peers in the control and awareness condition. Inspection of the protocols suggests that the process of combining two separate drawings into one shared drawing is a process that increases students' need for coordination. Scripts consisting of concrete subtasks might indeed alleviate the need for coordination, but the content of the specific subtasks (combining two separate drawings) in the present study increased the need for coordination. Often two objects or processes were presented in both individual drawings and so students had to decide which of the two similar objects they wanted to include in their final joint drawing. Furthermore, students had to decide which of the two students actually would cut and paste the objects, and decide on the location of the object on the shared canvas.

In the present study we explored the effects of awareness feedback and a script separately. The examples discussed above illustrate that on the one hand, the feedback from awareness features often provided students with information about the next best step to take and structured their learning process. On the other hand, scripts often increased students' awareness about their responsibilities, the interaction they engaged in, and the task they were expected to perform. Additional research is needed to explore how awareness feedback and scripts can be combined and how this combination can be fine-tuned to facilitate collaboration and learning by drawing in the best possible way. By including awareness feedback in the individual preparation phase of the collaboration script, the quality of students' initial individual representations might be further enhanced. Other options include the provision of real time awareness feedback on students' collaborative knowledge construction proves (for example their current coverage of the domain or participation) combined with tailored scripts that suggest specific task and actions that fit the need of a particular dyad.

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