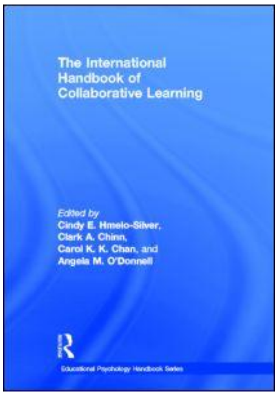

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Metacognition and Computer-Supported Collaborative Learning

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METACOGNITION AND COMPUTER-SUPPORTED COLLABORATIVE LEARNING

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Research on metacognition evolved from seminal papers by Hart and Flavell (Schwartz & Perfect, 2010; Winne & Nesbit, 2010). Hart (1965, 1967) investigated whether people could judge accurately what they know. He asked people questions about common knowledge. If they could not recall the answer, he asked them to estimate the likelihood they would recognize the answer among options in a multiple-choice question. In general, people were quite good at these tasks. Flavell (1971, 1979) urged investigations into what people perceived about (a) their memories and (b) operations they used to remember. He further theorized that people could inspect features of their knowledge, tasks they undertook, and methods for working on tasks. With information gleaned from these metacognitive activities and feedback about differences between goals and plans, he conjectured that people could choose or create more effective methods for making progress.

Models of metacognition and research that builds on those models open new lenses for examining how participants perceive and work in computer-supported collaborative learning (CSCL). We survey this area and suggest prospects for future research. Specifically, we begin by reviewing components of metacognition in solo activity and then distinguish it from co- and shared metacognition and regulation that ideally occur during collaborative activity. Then, we discuss factors implicated in promoting metacognition in collaboration and conclude with ideas for advancing research on the roles of metacognition in CSCL.

METACOGNITIVE MONITORING

Metacognition is commonly described as thinking about how one thinks, and characterizing cognitive products that cognitive operations create. For example, after studying the law of supply and demand, a learner might question the benefits of extra work to generate her own everyday examples of the law. Generating this question about benefits and answering it are elements of metacognitive monitoring. To monitor, features of a target are compared to a set of standards. In this case, the target is the cognitive work to generate examples of supply and demand; the standards refer to returns to the learner on that investment of effort, likely measured in terms of estimated memorability.

In addition to considering the general efficiency of generating examples when trying to learn abstract principles such as the law of supply and demand, metacognitive monitoring can also focus on a particular instance of cognition, how a particular example was generated. The products of metacognitive monitoring, in both cases, are metacognitive "knowledge." We have marked the word *knowledge* with scare quotes in the preceding sentence because, while that term is widely used, information generated by metacognitive monitoring sometimes does not meet everyday requirements for knowledge, namely, that knowledge is durable, retrievable, and accurate. In this case, the word *information* is more appropriate than knowledge (see Winne, 2010).

In analyzing metacognition that occurs in solo and collaborative learning, it is helpful to differentiate topics of metacognition. In our example, particular cognitive operations or tactics that generate examples or that lead to recalling examples, as well as the examples themselves, are located at what is termed the *object level*. People can apply cognition to their mental representations of these "objects." The learner can monitor attributes of cognitive tactics used to generate examples relative to standards such as effort and the likelihood operations yield cogent examples. The examples per se can be monitored relative to standards such as completeness and clarity. These monitoring operations occur at the *metalevel* because they are not the objects examined but, rather, they examine information about the objects (Nelson & Narens, 1990).

It is unfortunate, in our view, that the word *level* was used to differentiate object from meta. Level invites interpretations that metacognition is somehow a "higher" or more complex form of cognition than "normal" cognition. We hold a different view. Cognitive operations people apply are fundamentally the same at the object level and the metalevel. People have only one toolkit of basic or primitive cognitive operations. The difference between the object level and metalevel is not the operations applied to information; rather, what differs are the topics on which learners cognitively operate. The understanding a learner generates about a concept such as how evaporation occurs is information at the object level. The learner's estimate of how well evaporation is understood is information at the metalevel.

People use information in the world to design routines for learning (or scripts or production systems depending on one's choice of models of cognition) and for other cognitively demanding tasks. These routines are refined successively based on the results of using them. An example is learning to use mnemonic devices that improve memory. The first letter of colors in the visible spectrum can form a mnemonic—ROY G BIV—that encodes the colors' names in the order of their wavelengths (from longer to shorter). This schema for a first letter mnemonic can be adapted to music (Every Good Boy Does Fine and FACE for the notes on the lines and spaces of the treble clef) and geometry

(Chief SOH CAH TOA for the trigonometric relations of sine, cosine, and tangent). This view of cognition is optimistic because it allows that learners' cognitive and metacognitive capabilities can improve by experience.

METACOGNITIVE CONTROL

Learners use the results of metacognitive monitoring to guide choices about how to proceed in a current task and to plan for future tasks. Our economics student may opt to slog on, generating even more examples of the law of supply and demand, or he might choose another tactic—searching for examples in the Internet—because he predicts it is more efficient and just as effective. Exercising options is metacognitive control.

A second way to exercise metacognitive control is to change features in the external environment that constrain or support how one is working on a task. For example, our learner might shift from working solo and initiate an online chat to involve a peer in generating examples. A third expression of metacognitive control is selecting content for input to cognitive operations. Our learner might estimate that a better route to learning is to study his group's wiki rather than independently constructing possibly erroneous examples. A fourth way to exercise metacognitive control is changing cognitive operations (e.g., switching from generating examples to spaced rehearsals of the statement of the law).

When learners apply metacognition to monitor activity that leads to adapting tactics, reshaping environmental factors, selecting content, or revising standards for metacognitive monitoring, they can exercise metacognition "in the moment" if they aim to alter fine-grained features of engagement in a current task. Metacognition may, instead, lay a foundation for wholesale perceptions of this task or tasks like this, general beliefs and goals, and large-grained strategies for working on tasks in the same category as a current task. When fine-grained or large-grained adaptations concern how to carry out learning, learners are engaged in self-regulated learning (SRL).

METACOGNITIVE KNOWLEDGE

In the context of collaboration, metacognition concerns information about features in the collaborative work setting as well as views about her attributes and those of her collaborators. Standards can be set for five categories of information handily summarized by the acronym COPES (Winne, 2001; Winne & Hadwin, 1998), as we list below. To be considered metacognitive knowledge, information about these features must be durable and retrievable. Fleeting thoughts and one-time perceptions are not knowledge.

1. *Conditions* shape how learners approach their tasks. These might include the group's composition and whether the environment provides access to useful resources or the software is familiar. Some conditions may be malleable but may require some time for changes to be realized; for example, a learner's domain knowledge, epistemological beliefs, and skills for learning.
2. *Operations* manipulate information. Cognitive operations are internal to each learner. Round-robin reviews of progress at the end of each group session are an example of a group operation. Examples of standards for operations include load (effort applied) and the probability of an operation generating a particular product.

3. *Products* are information that operations create. Standards for products can be set externally, by a teacher or by each group member or negotiated by the group. For example, a group might set standards for its second meeting to (a) finalize the list of resources they will use and (b) ensure each member makes an equal contribution to group work.
4. *Evaluations* assign values to differences identified by metacognitive monitoring. For example, effort required to generate examples (an operation) can be valued as a sign of productive work or low ability (attribution theory; or, making frequent contributions to a chat may be motivating because it provides an arena for demonstrating competence or for deepening understanding by leveraging others' contributions (goal orientation; see Winne & Hadwin, 2008).
5. *Standards* can themselves be monitored. A person or group might examine standards for a project and conclude they are vague or picayune.

Calibration

The success of adaptive metacognition depends on two issues. First, metacognitive monitoring must be accurate: what the learner judges to be the case must match what is the case. The accuracy of this match is called calibration. Second, if metacognitive monitoring is well calibrated, the successful learner must accurately forecast outcomes that will be generated for each option that is available for expressing metacognitive control. These are outcome expectations.

In various contexts for solo learning, undergraduates can be quite poorly calibrated in judging what they have learned by studying. Not only are they inaccurate, but they are also inaccurate in a way that hampers development of knowledge in the domain of study (the object level). Specifically, overconfidence—predicting more knowledge than one has—characterizes learners with less achievement, underconfidence—predicting less knowledge than one has—is typically found among learners with higher achievement. The overconfident learner chooses a poor course of action (metacognitive control) in not changing tactics for studying or restudying when this would be beneficial. The underconfident learner suffers an opportunity cost either by spending unnecessary time restudying when new material could be studied or by changing tactics unnecessarily.

In the case of outcome expectations, learners and collaborators who have broad knowledge of tactics and strategies need to make optimal choices in changing conditions, operations, and standards in relation to products they forecast to be most useful to their task. Currently, we know little about collaborators' outcome expectations regarding group processes. While the theory is well structured, data to test it are meager (cf. Peterson & Schrieber, 2006).

METACOGNITION IN COLLABORATIVE TASKS: SELF-REGULATION, COREGULATION, SHARED REGULATION

In this section, we extend the view of metacognition from a solo cognitive activity to a collaborative context. Ideal collaboration is work that is coordinated and interdependent. In collaborative activities, learners strive to achieve a shared goal or solve a shared problem (Roschelle & Teasley, 1995). In contrast to cooperative work, where labor is divided among group members, genuine collaboration involves dynamic, mutually interdependent interaction intended to move the group toward a shared goal in a joint task (Dillenbourg, 1999). A collaborative team leverages individuals' unique and distributed knowledge and expertise to achieve a product that could not be achieved by individuals alone (Johnson & Johnson, 1999).

Success in collaborations depends on: (a) strategies and self-regulatory skills individuals contribute to the group, (b) support members provide to one another that facilitates individuals' self-regulatory competence (coregulation), and (c) shared or collective regulation of learning that involves metacommunicative awareness and successful coordination of strategies (Barron, 2003). From this perspective, collaborative work fuses individuals' distributed metacognitive work with shared and coordinated metacognitive work of the group.

Individuals in a group can metacognitively monitor and control their own personal knowledge and operations. This is metacognition in the service of self-regulation (Hadwin, Järvelä, & Miller, 2011). It maintains each individual's active and strategic involvement in the collaborative task.

However, collaborative work entails interdependence. Thus, each group member's participation depends on coordinated metacognitive knowledge, monitoring, and control exercised by team members. If one participant is off-track or not calibrated well in metacognitive monitoring or metacognitive control, this compromises collaborative work. Students coregulate learning by temporarily guiding, prompting, or assisting each other to accurately monitor and control cognitive work that contributes to the group product. Coregulation occurs, for example, when one participant prompts or questions another about metacognitive topics at the metalevel; or, when one student adopts another's metacognitive stance and makes a judgment about the peer's learning or thinking (Hadwin, Järvelä, & Miller, 2011). Coregulation implies reciprocity—group members assist each other to calibrate or realign one another's metacognition in the service of regulating contributions to the collaborative task. Thus, they distribute responsibility to optimize each group member's metacognitive activity and calibration.

Full collaboration implies meta-awareness of the coordinated whole. Successful groups are not only metacognitively aware of what individual group members are doing, they also unite their individual metacognitive information and control to negotiate consensus about task perceptions, goals, knowledge about group process, evaluations of collective progress and outcomes, and regulatory decisions about how to stay or get back on track. In addition to solo metacognition and coregulation of group members' metacognitive processes, shared metacognition underlies planning, monitoring, evaluating and regulating "in unison" (Hadwin, Järvelä, & Miller, 2011). Shared metacognition builds communal awareness of the conditions, operations, products, evaluations, and standards bearing on group processes and products. Metacognition that underlies shared regulation shifts the plane from "I" or "you" to how well "we" are working to accomplish "our" goal.

Fundamental Metacognitive Processes in Collaborative Tasks

Three central questions relate to metacognitive events in collaborative tasks: (a) What is monitored? (b) How are goals/standards for monitoring determined? (c) What is metacognitively controlled or regulated? Elaborations of these questions, in Table 26.1, provide a useful frame for comparing metacognition in self-regulation, coregulation, and shared regulation of learning when tasks are collaborative. Regulation occurs when metacognitive knowledge, monitoring, and control fuel individual or collective large-scale adaption of task perceptions, goals, plans, strategies, or approaches within one task or from one task to another.

Research on Metacognition in Collaboration

Metacognition per se and computer supports for metacognition are beginning to be examined in CSCL environments. Manlove, Lazonder, and De Jong (2006) examined solo metacognitive processes in collaborative work. Group members worked at separate work stations using Co-Lab (a collaborative computer based learning environment) and a process coordinator (PC) tool for setting, monitoring, and evaluating goals. For half the students, the PC tool was enhanced by providing a hierarchy of preset goals from which to choose, hints and explanations, and a template for the final report. The PC tool supported solo metacognition and a chat tool created a collaborative space for emergent regulatory conversation. Traces of planning, monitoring, and regulating were logged separately for each team member during the collaborative task, then aggregated across participants to examine relationships between collective (or averaged) metacognition and the quality group products.

Students who used the enhanced PC tool for planning, monitoring, and regulating engagement in the collaborative task: (a) collectively engaged in more planning, but not monitoring or evaluating activities, than students for whom tools were merely available, and (b) collectively performed better on a collaborative modeling task. In contrast to hypotheses, correlations between aggregate frequencies of planning, monitoring, and regulating and collaborative task performance were weak for both conditions and surprisingly higher for groups using the unenhanced PC tool. Importantly, Manlove et al. also coded and analyzed chat dialogues for instances of regulative talk. Participants who used the enhanced PC tool apparently had less need for regulatory talk in the chats. These data also afforded the researchers opportunities to uncover instances of coregulation in the group.

Iiskala, Vauras, and Lehtinen (2004) and Vauras, Iiskala, Kajamies, Kinnunen, and Lehtinen (2003) made important contributions in studies that examined metacognitive and cognitive interactions at the interindividual level (coregulation in collaboration). Grade 4 dyads were videotaped during a computer-based problem-solving game to study how peers mediate each other's regulated learning and metacognition. These researchers operationalized instances of metacognition as exchanges in which individuals monitored and regulated each others' contributions to a shared task. They used the term *socially shared regulation* to emphasize: (a) egalitarian distribution of monitoring across participants, and (b) the task as a joint problem-solving activity completed together rather than solo.

Metacognitive monitoring and control in this study tended to focus on participants' monitoring and controlling each others' perceptions or coming to understand each others' thinking and decisions, not monitoring and controlling shared knowledge and beliefs about the task and processes. From our perspective (see Table 26.1), this implies coregulation because participants assisted each other to accurately monitor and control the cognitive work they contributed to the group.

Examining socially shared metacognition has posed challenges for researching: (a) what is consistent across group members in terms of their distributed metacognition within the group, and (b) what is communal or shared in terms of group planning and regulation. A specific challenge is separating the individual from the collective, and

Table 26.1 Contrasting Self-Regulation, Co-Regulation, and Shared-Regulation of Metacognition in Collaborative Tasks

	Self-Regulated Learning in a Collaborative Task	**Co-Regulated Learning in a Collaborative Task**	**Shared Regulation of Learning in a Collaborative Task**
What is metacognitively monitored? • Task knowledge • Self knowledge • Goals and plans • Strategy knowledge • Strategy use	• My perceptions about the task (what we are supposed to do) • Strategies I know/use for this task • Progress toward goals and standards I hold for this task • How I think we should approach this task • Ways my actions influence the task	• Each of my team members' perceptions of this task • Strengths and strategies each team member knows/uses for this task • Goals and standards each team member holds for this task and progress toward those goals • Plans each team member has for this task and their work • Ways our actions and interactions influence each other and the task	• Common and negotiated perceptions of this task • Knowledge about our collective strengths and weaknesses for this task • Goals and standards we negotiate together for this task • Alignment between collective and individual goals • Strategies we choose to guide our collaborative process • Ways our actions influence our status and effectiveness as a team
How are standards for metacognitive monitoring determined?	Individuals hold personal standards against which they monitor their own progress	Individuals hold standards for themselves and others against which they monitor each other's progress	Collective standards are negotiated to align and maximize individual standards and monitor progress as a collective
What is metacognitively controlled or regulated? • Task knowledge • Self knowledge • Goals and plans • Strategy knowledge • Strategy use	• My perceptions about the task • My strategy knowledge • My strategy use • My goals and standards for this task • My plans for working together • Perceptions and evaluations of my progress • Calibration of self-monitoring	• Each other's task perceptions • Each other's strategy knowledge • Each other's strategy use • Each other's goals and standards for this task and for contributing to this task • Each other's plans for this task and for contributing to this task • Awareness of other's roles and actions in this task • Perceptions and evaluations of each other's progress • Calibration of other-monitoring	• Our negotiations of a common task perceptions • The common perceptions we hold for this task • Knowledge of this group's strengths and weaknesses with respect to this task • Shared goals • Alignment of individual task perceptions and goals • Our use of team processes and strategies for succeeding with this task • Knowledge about strategies we have used together and their effectiveness • Perceptions and evaluations of our collective progress toward the goals/standards we have negotiated for this task • Calibration of collective monitoring

shared metacognitive activity from shared cognitive and problem solving activities. For example, when collaboration is prompted with scaffolds such as "I need to understand …," "My theory …," or "A better theory …" shared cognition for constructing knowledge in a domain is supported. In contrast, scaffolds such as "Our goal is …," "We need to understand why we are doing this problem," or "Our best strategy might be …" focus on developing shared metacognitive knowledge about the task, goals, and strategies.

Students clearly engage metacognitive processes in the context of collaborative problem solving (Hurme & Järvelä, 2005) when constituent metacognitive knowledge and metacognitive skills are distributed among individuals (Hurme, Palonen, & Järvelä, 2006). However, in group problem solving, different types of metacognitive events emerge, including metacognition becoming shared, metacognition becoming visible but not shared, and individuals sharing metacognition by attempting to regulate joint activity (Hurme, Merenluoto, Salonen, & Järvelä, submitted).

Hurme, Merenluoto, and Järvelä (2009) examined shared metacognition when groups of three preservice primary teachers worked together to solve mathematical tasks. Students worked online using an asynchronous learning environment (WorkMates) and exchanged text messages. Messages were coded for evidence of metacognitive activity when three criteria were met, namely when a message was: (a) related to and focused on earlier discussion; (b) intended to interrupt, change, or promote the progression of joint problem solving; and (c) explicit about reasoning for considering an alternative. From the perspective of Hurme et al. (submitted), metacognition was shared when individual metacognition was made explicit to the group and intended to shift the group's collective approach. In other words, as per Table 26.1, what was controlled or regulated was group planning. The group problem solving process was monitored but what fueled a shift in the group's plan was a team member self-monitoring her strategy and sharing results with the group. That is, shared metacognition built on individuals' metacognition.

In contrast to this approach to examining shared regulation, Hadwin, Malmberg, Järvelä, Järvenoja, and Vainionpää (2010) examined shared metacognition in the context of task perceptions and goals for collaborative work. Participants included three triads of graduate students collaborating on three consecutive online collaborative tasks using the nStudy software (Winne, Hadwin, & Beaudoin, 2010). Shared task perceptions and shared goals were examined by contrasting: (a) notes co-constructed about planning and reflection that were submitted by each group at the beginning of each task, and (b) convergence among group members' individual reflective statements about goals they held for the task they had just completed. Findings indicated that shared metacognition was rarely achieved and did not evolve across tasks. In this study, juxtaposing co-constructed goal statements for the task with data about each group member's individual goal for the task was useful in revealing shared metacognition.

PROMOTING METACOGNITION IN COLLABORATION

We posit that researchers and practitioners need to attend to several factors that potentially afford and constrain metacognition and collaboration: task structures, technological tools, and interpersonal support.

Tasks

To prompt and support metacognition and regulation, tasks need to be at an intermediate level of difficulty. This affords and requires mindful attention to task demands and collaborators' characteristics, as well as thoughtful use and evaluation of tactics and strategies selected to close gaps between current conditions and goals. Classroom research has linked appropriately complex tasks to opportunities for and evidence of metacognition and regulation of learning (Many, Fyfe, Lewis, & Mitchell, 1997; Perry, Phillips, & Hutchinson, 2006; Perry, VandeKamp, Mercer, & Nordby, 2002; Walker, Pressick-Kilborn, Arnold, & Sainsbury, 2004). Perry and colleagues characterized tasks as complex when they addressed multiple goals, focused on large chunks of meaning, and extended over time. Such tasks engage learners in a variety of cognitive and metacognitive processes and afford creating a broad range of products as evidence of learning (Bruning, Schraw, & Ronning, 1995; McCaslin & Good, 1996; Turner, 1997). Succeeding at challenging tasks is motivating—it increases self-efficacy and the likelihood that learners will persist in the face of difficulty. Perry's research links teachers' design and the implementation of complex tasks to metacognition and the regulation of learning in solo and collaborative settings.

Walker et al. (2004) examined an intervention designed to promote metacognitive monitoring, collaborative learning, and regulation of learning in a context of teacher-scaffolded instruction. Learners were Grade 5 students studying society and the environment by engaging in projects using information and communication technologies (ICT) to search for information on the Internet. Data included assessments of students' ability to plan a research project and use ICT, and teacher achievement ratings of students' products. Assessments of planning and ICT use included assessments of metacognitive knowledge monitoring. Observations recorded teacher scaffolding, collaborative group functioning, and regulatory discourse. Compared with students in control classrooms, those in the intervention were characterized as "advantaged" in terms of their achievement, ICT skills, planning skills, and accuracy in metacognitive knowledge monitoring. Moreover, observations of collaborative group functioning illustrated collaborative monitoring and evaluation of the quality of work against agreed-upon standards, plus coregulatory actions that promoted persistence and sharing ideas to overcome challenges.

We note that tasks characterized as collaborative in the CSCL literature reflect a continuum of communication between and among learners. At one end of the continuum, collaboration involves consulting or coregulating as group members complete individual tasks, as was the case in the study reported by Choi, Land, and Turgeon (2005). At the other end, learners work together to develop shared understandings of task conditions and standards, and to coconstruct processes and products that complete tasks, as in Hadwin et al.'s (2010) study. Shared metacognition and shared regulation to optimize performance and problem solving are unlikely or, at least, not assured in the first case, but are required in the second case. Also, complex tasks that challenge learners' individual zones of proximal development in intellectually rigorous activities (Englert & Mariage, 2003; McCaslin & Good, 1996) are more likely to prompt interdependence among group members that engenders metacognition and self- and shared regulation than unidimensional task structures.

Hurme and Jarvela (2005) studied metacognition and CSCL as students worked on "projects" in geometry and probability. Participants were 16 students (aged 13) in a secondary school classroom in Finland. Working in dyads, students used Knowledge Forum (KF), the current version of the earlier Computer-Supported Intentional Learning Environment (Chan, chapter 25 this volume; Scardamalia & Bereiter, 1996) that includes a discussion forum where participants can post text and graphical notes, and comment (build) on their partners' notes. Students in dyads posted solutions to problems as notes, commented on the correctness of their partners' solutions, and discussed alternative solutions or paths to solutions. The teacher instructed the students to make their thinking as visible as possible and was available to facilitate networked discussions if needed, but the researchers commented that "her role was minor in the discussions" (p. 52).

Hurme and Jarvela (2005) were interested in how students shared knowledge and regulated cognition during CSCL. They found that the students shared math concepts as well as strategies and heuristics for solving math problems. Evidence of metacognitive knowledge and metacognitive monitoring was found in networked notes, although there was more evidence of metacognitive knowledge than metacognitive monitoring. Perhaps students did not need to monitor—which raises the question of whether the problems were challenging enough to prompt monitoring—or the knowledge was easier to make visible than to monitor. It is also possible that the students needed more explicit prompting to monitor, either from the teacher or by the software. We will take up this topic again when we discuss interpersonal support for metacognition in collaboration.

The researchers noted an important constraint on students' collaboration in these projects: mathematical symbols could not be entered into notes in Knowledge Forum. The researchers speculated that this limitation of the software was likely to have prompted the students to add narrative detail to their notes, which affords metacognition but may also have decreased their use of mathematical symbols, the language of math, and the accuracy of arguments in shared notes. Hurme and Jarvela characterized the majority of students' exchanges as "mainly 'everyday talk' rather than attempts to argue using mathematical concepts" (p. 68). This aligns with other research—left on their own, most students do not develop optimal self-regulation (Zimmerman, 2008), which may signal the need for more explicit scaffolding of self- and shared regulation, as we have already suggested. Finally, Hurme and Jarvela noted there was no evidence students used collaborations to improve problem solving. Depending on their goals (i.e., communication in the service of completing independent or shared tasks), this may not be a limitation as shared metacognition and regulation need not always enhance individual regulation and performance. Their report is unclear about whether every student was expected to provide a solution to the problems or could share solutions. A focus for future research on metacognition in collaboration should be to understand and clarify outcomes for individuals and groups, and key elements for accurate calibration. Researchers should also attend to differences in synchronous versus asynchronous collaborations. Collaborations were asynchronous in the Hurme and Jarvela study. Tools that allow synchronous collaboration through, for example, online chats and discussion forums and shared workspaces, would seem to be ideal for shared metacognition and regulation (e.g., Virtual School; Carroll, Neale, Isenhour, Rosson, & McCrickard, 2003), but shared metacognition and regulation may also be supported in asynchronous environments such as wiki spaces and discussion forums when collaborators are prompted specifically to negotiate and reach consensus about metacognitive aspects of the task such as task perceptions and task goals.

Technological Tools

The CSCL literature invites a critical question: "Are technological tools instrumental to learners' metacognition or collaboration and, if so, how?" In Walker et al. (2004), support for metacognition and collaboration was provided through teacher–student and student–student interactions but we cannot identify how software contributed to this. In a study reported by Hurme and Jarvela (2005), students communicated about their projects using software, but their metacognitive and collaborative activity may have been just as rich had they engaged in face-to-face discussions. Again, it was the teachers' instructions that prompted the students' metacognitive activity.

Soller, Martinez, Jermann, and Muehlenbrock (2005) identified three classes of tools for supporting metacognition in collaboration: mirroring systems, metacognitive systems, and guiding systems. Mirroring systems (e.g., ART/SAILE; Goodman, Geier, Haverty, Linton, & McCready, 2001) collect and aggregate data during students' collaborations and reflect it back to them (e.g., as a graphical representation). These systems are designed to raise learners' awareness of their thoughts and actions, but the locus for metacognitive engagement and regulation lies in students, or teachers, who must monitor differences metacognitively between products and standards, then exercise metacognitive control to change conditions, operations or standards so the goal can be met. Metacognitive systems (e.g., Sharlock II; Ogata, Matsuura, & Yano, 2000) display standards for desired interaction along with information about the current state of collaborations. With these data, collaborators can monitor and adjust their interactions. Again, the locus for metacognition and potential regulation is with students, teachers, or coaches. Guiding systems (e.g., DEGREE; Barros & Jerdejo, 2000) perform all the phases in a typical regulatory loop. These systems record and analyze data as collaboration occurs and evaluate whether the form of current interactions will achieve the desired goal. As possible, they offer advice or guidance about how interactions can be adapted. Finally, they evaluate outcomes from their interventions and begin again in the first phase of the loop. According to Soller et al. (2005), an ideal system might be one that progressively moves the locus for regulation from the system to the students—a transformation from guiding tool to metacognitive tool and then to mirroring tool. We suggest that an ideal tool would adjust these levels of support in just-in-time fashion aligned to the state of the learners' metacognitive and collaborative activites. Virtual School is an example of a system that takes steps in this direction (Carroll et al., 2003). We also note that ideal systems will not only achieve this flexibility but also, unobtrusively, collect data that researchers need to advance the field (Winne, 2006, 2010).

Interpersonal Support and Scaffolding

In much of the research we have cited, software was neither a necessary factor nor a sufficient factor in accounting for observed metacognition and collaboration. Usually, instrumental support came from teachers or peers. For example, Walker et al. (2004) reported that teachers provided extensive scaffolding that led to outcomes. Hurme and Jarvela (2005) made little mention of teacher support in their study, but the classroom in which they were working appeared to be focused on complex tasks, higher order learning, and collaboration (projects for pairs and small groups), and the teacher explicitly prompted students to be metacognitive. Less clear is whether the teacher in this classroom monitored and scaffolded metacognition and collaboration after initial instruction.

Hurme and Jarvela (2005) offered more extensive analyses and examples of how students supported one another's metacognition in collaboration than Walker et al. (2004), while both studies had positive results concerning learners' collaborative monitoring and coconstruction of standards and strategies. However, Hurme and colleagues (Hurme & Jarvela, 2005; Hurme, Merenluoto, & Jarvela, 2009; Hurme, Palonen, & Jarvela, 2006) expressed disappointment that much of what they observed involved "everyday talk" with low levels of metacognitive activity (e.g., planning). One reason for this may be the typically low levels of support for metacognition and collaboration that students received in CSCL environments from teachers or software. We observed that instructions about metacognition were vague (e.g., make your thinking visible) and students received little or no guiding feedback from teachers or from software about the quality of their interactions or their progress on tasks. Metacognition and regulation were left to "unfold."

A reliable finding is that productive communication, metacognition, and regulation are unlikely without the support that helps collaborators forge effective participation structures. Makitalo-Siegl, Kohnle, and Fischer (2011) demonstrated this in their study of how high and low levels of teachers' scaffolding affected secondary school students' help-seeking and science learning. Students who received high levels of scaffolding required less help and learned more. Left on their own, learners seemed less inclined or less capable of monitoring and regulating their engagement metacognitively by refining perceptions of tasks, adapting goals, or revising plans for learning. Pressures for grades, lack of feedback about procedures, and low accuracy in tracking how they work (Winne & Jamieson-Noel, 2002) limit opportunities for students to improve learning and collaboration. Thus, they work below optimal levels (Winne & Jamieson-Noel, 2003) as they try to discover how well they are doing and what worked well versus not so well (Hadwin & Winne, 2012).

A challenge for CSCL research is to design software systems to support metacognition and collaboration in ways that parallel or extend what effective teachers and competent peers do. Soller et al. (2005, p. 274) characterize this challenge as one of "(a) defining, as best possible, a model of desired interaction, and (b) designing algorithms that measure the degree to which the current model of interaction meets the requirements of the desired model, which [is often] uncertain and unstable." They go on to argue models of "productive interaction" derived from understandings about factors that affect learning positively. Judgments concerning these qualities of students' interactions require skilled subjectivity (see Brown & Campione, 1994) which software may not be able to achieve.

While software can prompt collaborators about metacognitive matters, for example standards for examining a group process, software almost surely cannot match people's ability to shape both group processes and collaborators' thinking about those events. Systems like those described by Carroll et al. (2003) and Soller et al. (2005) may scaffold metacognition but, for the present, productive interventions in students' metacognition about CSCL probably require melding guidance from mentors and software (Dennen & Hoadley, chapter 22 this volume). To examine metacognition fully in collaborative enterprises, researchers should gather data from all parties, including mentors, in both collaborative and solo settings.

ADVANCING RESEARCH ON ROLES AND EFFECTS OF METACOGNITION IN CSCL

Software technologies offer many benefits. They can help collaborators search for and organize information solo and collaboratively, and prompt learners to consider features of their work metacognitively across levels of self, co-, and shared regulation. Today's technologies also can, unobtrusively, log data about almost every observable facet of these events in formats that are ready immediately for further, sometimes automated, analysis. Researching metacognition and its roles in computer-supported collaborative learning still poses challenges because it is very difficult to operationally define and record two key complex metacognitive events—monitoring and decision making that underlie metacognitive control—without knowing something about the standard(s)/goal(s) and the judgment(s) individuals make about progress.

Here, we have space to examine briefly three issues important for future research on this topic: modeling metacognition, analyzing *trace* data about metacognition and supporting collaboration in collaborative settings. Before addressing these, however, we note three requirements for progressive research programs on the forms and roles of metacognition in CSCL. First, to exercise metacognition, collaborators must have *options* for managing solo and collaborative work. Options for operating on information, establishing collaborative agendas and procedures and so forth may be trained by a researcher or simply "brought" to the setting by the collaborators. Second, productive regulation requires *feedback* about the topic(s) and task(s) on which learners collaborate as well as the features of collaboration itself (Butler & Winne, 1995; Winne, 2011). Feedback may be provided by software without mediation by a researcher (other than having designed the software in the first place) but tracking feedback among collaborators and between collaborators and their mentors should not be overlooked. Third, the collaborative environment must at least afford and preferably support *collaborators' experimentation* with options for carrying out their individual and shared work. This extends beyond merely trying out various options. It means at least having genuine opportunities plus explicit permission to redesign and even evolve replacements for initial forms of the conditions, operations, and standards that characterize a collaborative enterprise. Even more helpful would be support in the form of tools that help collaborators design experiments, and track and analyze data they generate as they put self-, co-, and shared regulation into practice.

Modeling Metacognition

Metacognitive monitoring requires collaborators to: (a) perceive task conditions accurately, including their collaborators' mental states; (b) assemble a set of standards, which are negotiated in fully collaborative work, against which products and processes at the object level are examined; and (c) ascertain differences accurately between features and standards. To exercise metacognitive control, collaborators must: (a) search memory and perhaps external resources for operations—cognitive and group processes—beyond those already used; (b) generate outcome expectations about the products each (set) of the operation(s) yields; (c) metacognitively monitor whether an expected product's profile is a better match to standards than the product generated by past or possible future candidate operations; and (d) if there is no clearly superior candidate for what to do, weigh the pros and cons of the possible candidates and operations to decide what to do.

Modeling metacognition fully requires data about all these topics. Gress, Fior, Hadwin, and Winne (2010) catalogued methods used in CSCL research published between 1999 and 2006. Varieties of self-reports (surveys, interviews), discussions and dialogues, and collaborators' feedback to instructors were overwhelmingly dominant. Self-report data from surveys and think-aloud protocols contribute to modeling metacognition in

CSCL because information gathered using these methods may match what collaborators have "in mind" as they work. We write "may match" because there are many reasons to question the veridicality of self-reports—biases and heuristics shape recall and on-the-spot interpretations (see Baron, 2008) in ways that render them inaccurate in various ways, even when self-reports are gathered as think-aloud concurrent with collaborators' work (see Winne, 2011, 2010; Winne, Jamieson-Noel, & Muis, 2002; Winne & Perry, 2000). Rather than relying on collaborators' interpretations of behavior, researchers need data that describe behavior per se. For example, did the collaborators negotiate a shared goal? What did the collaborators do to negotiate a shared goal?

Analyzing Trace Data about Metacognition

Suppose a CSCL environment provides a tool for collaborators to apply various tags to information they contribute to a chat (e.g., Winne & Beaudoin, 2009). During a chat, Lucy tags Sara's contribution, "Let's survey parents" with "vague goal." Lucy's tag traces metacognitive monitoring of Sara's input. The particular tag she chose among several available tags (e.g., "important," "review for work agenda") reveals the standard she used to monitor. Applying a tag rather than doing something else (e.g., making a note, surfing for a published parent survey) identifies how Lucy exercised selective metacognitive control.

Trace data are observable markers of cognitive events generated as collaborators study solo and work together (see Winne, 2011). Carefully designed features of an interface and cognitive tools allow trace data to be gathered unobtrusively. Gress et al. (2008) reported that traces were used infrequently in CSCL research. We recommend more use of trace data because they complement other kinds of data and do not suffer the shortcomings just described for self report data.

Trace data about metacognition in CSCL can be modeled by an *If–Then* pattern (see Winne, 2010). For example, *If* a contribution to a chat is judged a vague goal and Lucy tags it "vague goal," Sara might *Then r*espond, "Why do you think so?" as a request for Lucy to share the standards she used to monitor metacognitively the earlier suggestion to survey parents.

Patterns of *If–Then* traces can be analyzed in two steps. First, traces are listed in order of their occurrence. This creates a timeline (see Figure 26.1). Second, a matrix is created that can represent transitions across adjacent traces. Each row of the matrix identifies one kind of trace logged by CSCL software; for example a contribution to a chat: "Check facts." Columns of the matrix are the transpose of rows. A tally in a cell of the matrix describes a transition from (a) the first trace in the sequence, identified by the cell's row, an *If*; to (b) the next trace represented by the cell's column, a *Then*. For example, *If* the first trace is an A (in Figure 26.1), *Then* the second trace is a B. Therefore, a tally is made in cell [A,B] to represent the transition from A to B. Trace B now takes on the role of the first trace at this point in the sequence, an *If*. It is followed by a *Then,* which is trace D in Figure 26.1. A tally is recorded in cell [B,D]. Trace D is now the *IF*, and so on.

The sum of tallies across a row describes the incidence of each trace in the corpus of data. Figure 26.1 shows that trace A occurred 3 times. This sum can be normed (divided) by the total of tallies in all row totals to represent the percentage of all traces that were observed in that category. Norming a cell's tally by dividing it by the sum of tallies across cells in a row describes the conditional probability of the column trace (*Then*) given the row trace (*If*). For example, the conditional probability of D given B, Event Sequence: A B D B C E D B C E D A C E D A B C F ...

Transition Matrix

	A	B	C	D	E	F	sum
A		//	/				3
B			///	/			4
C					///	/	4
D	//	//					4
E				///			3
F							0
							18

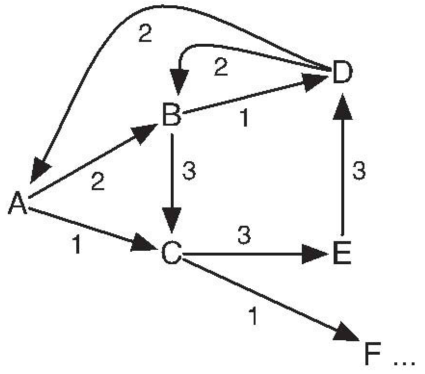

Figure 26.1 A sequence of events, the transition matrix, and a graphical display of the pattern represented by the sequence.

Pr[D|B] = 0.25. Generalizing, whenever the group produces a trace of type B (an *If*), odds are 0.25 the next trace will be a D (a *Then*).

A “picture” of a transition matrix (technically, a graph; Figure 26.1) can depict how a group expresses metacognitive activity. Weights (numbers) on the edges (arrows) of this graph show the frequency of a transition corresponding to cells with tallies in the transition matrix. Several quantitative indexes can be computed using these data. They describe, for example, the degree to which different contexts (*Ifs*) trigger the same expression of metacognitive control (*Then*). See Winne et al. (2002) for elaboration. Future CSCL research should investigate patterns of metacognition underlying collaborators’ self-, co-, and shared regulation of work. Trace data and trace-based descriptions about patterns of collaboration may also be a rich source of feedback to collaborators. More than simple frequency counts, patterns represent context that must be tracked to examine metacognitively what might be changed to improve work (Winne, 2011).

Focusing Collaborators’ Metacognition on Facets of Tasks

As noted earlier, we found few CSCL systems that truly support metacognition in collaborative activities. The COPES schema introduced earlier maps categories about which basic support might be provided. Helping collaborators identify factors of conditions and consider how conditions might affect collaborative work might be accomplished in various ways; for example, a warm-up checklist or a wrap-up exercise where collaborators are invited to consider conditions. A “smart” system might track features in online chats where the group “thrashes” as traced by scripted contributions (e.g., chosen from a dropdown list; see Beaudoin & Winne, 2009) like “What do you mean?” or “How did you get that” appearing with high conditional probability in relation to the topic of collaboration. Operations might be brought to the fore by training collaborators to use a branching script for collaboration, which can then become an object of metacognitive enquiry. In short, providing tools that directly invite metacognition, such as tags, and signaling simple activities that entail metacognitively examining the collaborative process will generate data needed to explore roles for metacognition in CSCL at the same time that variations in these scaffolds might be the focus of experiments on how they affect the quality and efficiency of collaboration. Capabilities of modern software to log extensive, fine-grained, time-stamped data about how collaboration unfolds in the context of options such tools afford (e.g., see Carroll et al., 2003; Soller et al., 2005) hold significant promise to widen and deepen research on CSCL as well as learning through CSCL.

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