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Computer-Supported Collaborative Learning
DOI 10.1007/s11412-010-9104-6

An information processing perspective on divergence and convergence in collaborative learning

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Received: 14 June 2010 / Accepted: 10 December 2010
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Abstract This paper presents a model of collaborative learning that takes an information processing perspective of learning by social interaction. The collaborative information processing model provides a theoretical basis for understanding learning principles associated with social interaction and explains why peer-to-peer discussion is potentially more effective than instructor-student discussion. The model explains information divergence as a key process for collaborative learning and information convergence as a key group process for addressing specific learning outcomes.

Keywords Learning · Collaboration · Information processing · CSCL · Divergence · Convergence · Collaborative learning · Cooperative learning · Social interaction · Online discussion · Group learning · Learning theory

Introduction

Some researchers speculate that the increased cognitive load of dealing with group members results in less efficient task performance by groups (Sweller et al. 2007). Such *process loss* in group performance is contrary to findings of learning benefits from peer collaboration (Wiley and Bailey 2006). Collaboration has been repeatedly shown to support and improve some types of classroom learning (e.g., Johnson and Johnson 1994; Mugny et al. 1975; Yeager et al. 1985). Compared to non-collaborative learning activities, collaborative learning fosters shared understanding, better information retention, and deeper processing (Garrison et al. 2001; Johnson et al. 1981; Slavin 1992). Other research supports the assertion that collaborative learning can promote higher-order learning such as critical thinking (e.g., Anderson et al. 2001; Gokhale 1995; Meyer 2003; Webb 1989). Although such research has encouraged learning by peer collaboration, the identification of learning-environment characteristics that affect collaborative interaction remains an important research goal. Wiley and Bailey (2006) suggest that variables of collaborative

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learning, including task coordination, group interdependence, and amount of argumentation, may determine whether a group learning activity displays process loss or gain. Research can help identify and confirm the effects of such variables, but researchers require a theoretical model to suggest variables and principles that warrant investigation. A model of collaborative-learning discussion is required to direct research; otherwise research efforts lack a predictive model from which to derive and test salient hypotheses.

Various theoretical perspectives from different disciplines form the basis of past investigation of collaborative learning because such learning comprises the diverse topics of human cognition and social interaction. The models of basic memory function and information processing do not generally address social interaction. Models from social and developmental psychology do not reference or derive concepts and principles from basic memory theory or from an information processing perspective. The theoretical perspectives of discourse and social interaction suggest constructs useful in answering questions about how best to judge and design collaborative-learning environments, but only by referencing the theoretical constructs and principles of basic cognitive functioning found in memory and information-processing theory can compelling and comprehensive explanatory models be developed. This paper reviews theories from both basic cognitive research and social-interaction research and proposes a model of *collaborative information processing* that provides a foundation for the investigation of collaborative learning, from an information-processing view of social interaction.

Information processing models of individual cognition and learning

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Information processing (IP) models describe thinking and learning in terms of cognitive processes that reflect and explain how individuals process, store, and use information. Mayer (1996) sees the IP model as describing cognition and learning in terms of *mental processes and representations* that are similar to the operations and information storage of computers. Human cognitive processing can be viewed as the application of information-processing operations on symbol structures (Mayer 1996).

Pinker (1997) provides a "computational theory of mind" that views human cognition as primarily the processing of information. From this perspective, human learning is the processing of information, uniquely including symbolic information, which results in new stored information. Newell and Simon (1976) proposed the physical symbol system hypothesis, which states that the symbol processing system is necessary and sufficient for intelligent behavior. Computer program models of cognitive architectures, such as Newell's Soar or Anderson's ACT (Newell 1990) rely on symbolic-information storage and processing to model human cognition and learning (Langley et al. 2009). The success of computer programs in mimicking human behavior, such as problem solving, support the assertion that higher-order human cognition is essentially a symbol-processing task.

Dual-store memory model

An influential memory model is the two-store (or dual-store) model introduced by Atkinson and Shiffrin (1968). The model distinguishes two functional memory components with different characteristics: short-term memory (STM) and long-term memory (LTM). STM is able to process and (temporarily) store information, but variations in the type and amount of processing done affect STM storage capacity. LTM, on the other hand, has a very large storage capacity and long retention, but has limited ability to process information.

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The dual-store model describes *control processes* that control the operation of and interaction between the two types of memory. Key control processes include *maintenance rehearsal*, which keeps information in the STM under the control of the individual, and *elaborative rehearsal*, the process by which newly-sensed information is associated with existing knowledge. The amount and type of information stored in LTM depends on elaborative rehearsal (Craik and Watkins 1973; Raaijmakers and Shiffrin 2004). Raaijmakers (1993) views maintenance rehearsal and elaborative rehearsal as equivalent to the primary and deep levels of processing proposed by Craik and Lockhart (1972), who hypothesize that the amount and type of cognitive processing done by an individual affects how and how well information is stored in that individual's memory.

IP and memory models of human learning thus explain that information is internalized as knowledge via elaborative rehearsal. Novel information perceived in STM is elaborated with information already present in LTM, resulting in information that is not identical to information from either source. This elaborated information, based on the perceived information and prior knowledge, is the basis for new knowledge encoded into LTM. The dual-store model thus predicts that the degree of association between newly perceived and previously learned information affects learning.

Cognitive models and architectures

Other cognitive models expand the functional information processing components beyond those established by the dual-store memory model. The concept of STM has broadened from a storage function to a processing function labeled working memory (e.g. Craik and Lockhart 1972). Models such as the Interactive Cognitive Complexity (ICC) learning model of Tennyson and Breuer (1997) include a *knowledge base* that is the repository for previously acquired information (similar to LTM). The ICC model, however, specifies different types of knowledge stored in the knowledge base: declarative, procedural, and contextual (Tennyson and Breuer 1997).

Cognitive models also differ in their descriptions of control processes. The processes of the ICC model include differentiation, integration, and construction. These processes elaborate and alter information in a learner's knowledge base based on sensory input of new information and an individual's affective states (Tennyson and Breuer 1997). Mayer (1996) lists three control processes affecting how information is stored: selecting, organizing, and integrating. Integration is a process implying the merging of stored and newly perceived information (as specified by elaborative rehearsal in the dual-store model).

Cognitive architectures model human cognition using software structures that mimic working memory and knowledge bases that include long term storage of semantic and procedural knowledge (Langley et al. 2009; Newell 1990). Cognitive architectures such as Soar (Newell 1990) include an elaboration phase in which existing knowledge from a knowledge base is brought into an analog of working memory (Newell 1990). Cognitive-learning models and cognitive architectures thus emphasize elaboration of information as a key process for learning and decision making.

Individual learning and conceptual conflict

An IP model of cognition can be combined with the idea of cognitive conflict to explain learning in individuals as processing to resolve conflict between perceived and stored information. Cognitive conflict is similar to ideas from other perspectives including equilibration described by Piaget (De Lisi and Goldbeck 1999). Humans have the cognitive

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ability to compare external symbolic representations (as perceived) with stored internal representations that establish meaning for the individual. To make this comparison, the individual must first access internal representations that can be compared to the newly perceived representation. Comparison is facilitated if the perceived representation is similar to existing stored representations (e.g., if both are expressed with the same symbol system or in the same context). If the external representation is very different than representations in LTM, then the individual may not be able to access similar stored representations that can be used to generate, via a process such as elaborative rehearsal, an internal representation (i.e., the newly perceived information is meaningless) and no comparison or alteration of stored representations will occur (i.e., no learning will occur).

If the perceived representation is very similar to what is recalled from LTM, no learning will occur, as the perceived information is equivalent to stored representations and no further processing will be done. The perceived representation does not sufficiently *conflict* with stored representations. The stage is set for individual learning only when a perceived representation is sufficiently similar to internal representations but also different enough to stir representational conflict. To resolve the conflict, a learner will generate a new representation that elaborates and integrates the conflicting internal and external representations. If the individual sufficiently processes the newly generated information (e.g., via elaborative rehearsal) the new or altered representations are stored in LTM (i.e., learning occurs).

Externalizing and internalizing information

Cress and Kimmerle (2008) conceptualize learning in terms of the cognitive processes of externalization and internalization of information. Internalization involves the perception and encoding of new information from sources external to the learner, including social interaction. These sources often use symbol systems to store and communicate information (e.g., spoken and written language). Information from external sources is integrated into the knowledge base of individuals via control processes such as elaborative rehearsal. Internalized representations are combinations of the source information merged with (and altered by) the learner's prior knowledge. Creation of such internalized representations can be quite automatic; it does not require higher-order cognitive processing or directed effort and attention, though those factors may affect internalization.

Externalization is the act of *expressing* representations of knowledge stored in memory, often through a symbol system such as language. To be expressed, stored representations must be processed by working memory using associated information retrieved from LTM. Cress and Kimmerle (2008) assert that the act of externalization itself can result in learning, because the cognitive effort of making such representations requires cognitive processing (such as clarification) of the externalized information. This learning-by-expressing process underlies the value of social interaction (such as CSCL discussion) for learning because students must externalize their thoughts (e.g., using language) in order to be understood by other students.

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Theories of learning by social interaction

Humans learn a great deal from other humans. Information stored in media such as books and videos enable a one-way transfer of information to a student and are the basis for much individual learning. When communication is extended and interactive, the potential for learning is thought to increase and is described as social interaction. Several theoretical perspectives, deriving from developmental and social psychology, have been offered to explain how such social interaction affects learning.

Social constructivist theory

Social constructivist theory, often mentioned as a basis for collaborative learning (e.g., De Wever et al. 2006; Hammond 2005), emphasizes the importance of social interaction for learning. The key point supporting collaborative learning from a social constructivist perspective is that learning is primarily a social activity of knowledge co-construction. Humans learn best through social interactions using their rich symbolic communication skills because social relationships establish the meaningful aspects of cognition.

Lev Vygotsky suggested that learning occurs when people use words, activities, and cultural tools to represent objects and events with and for learners (Ormrod 2004). After repeated social interaction, representations and concepts of one individual are internalized in another (Vygotsky 1986). People's internal thought processes and structures involving symbols originate in their previous social interactions (Stahl 2000). Q2 Social interaction is a highly effective way to internalize new representations because social interaction is the method used by human children to initially internalize symbolic (e.g., cultural) knowledge (Vygotsky 1978). Because children initially obtain their symbolic representations through social interaction, it remains a most effective means of internalizing and processing symbolic information throughout childhood, adolescence, and adulthood.

The theoretical perspectives originating in developmental and social psychology, and from discourse analysis, do not take an information processing perspective on cognition and learning. Such a perspective requires explaining cognition and learning via processes that identify and transform information. Nor do the classic developmental and social theories reference cognitive structures and processes identified by basic memory theory. While these theories may offer useful descriptive insight about learning principles, they do not have the explanatory power of a theory formulated in terms of basic theoretical cognitive processes empirically established and adopted as part of information processing models. The information processing perspective has the potential to unify social interaction for learning with more foundational cognitive processes.

Theories of group elaboration

Elaboration is a concept accepted as important in the analysis of learning from various theoretical perspectives. The definition and essential characteristics of elaboration, however, vary with different theoretical perspectives. Slavin (1996), for example, describes a cognitive elaboration perspective that recognizes the importance of cognitive elaboration for learning. On the surface, such recognition seems in agreement with the information processing concept of elaborative rehearsal. A close examination of these concepts reveals some differences. Educational researchers tend to see elaboration as a positive process such as deepening of understanding or an enhancement of meaning that results mainly from a conscious, intentional, goal-directed effort, such as explanation (Slavin 1996). Elaboration, in which groups try to elaborate ideas, is also seen as an "active" process that results in, or improves, knowledge. (For an example of this view of elaboration see Whitney 1987). An information processing perspective tends to see elaboration as a diversification of information that is neutral (not an improvement or deepening of information) based upon

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individual prior knowledge. Such generated information may be true or false, and may increase insight but may just as well lead to misconceptions.

Theories of socio-cognitive conflict

Researchers such as Johnson et al. (1998) and Slavin (1987) suggest that students who work together cooperatively obtain learning advantages. Cooperation alone, however, may be insufficient to ensure higher-order learning (Slavin 1992). Paradoxically, factors thought to improve peer-to-peer learning include increased group *conflict* (socio-cognitive conflict). Social psychologists have speculated on the utility of conflict and investigated its effects in collaborative learning situations (Buchs et al. 2004). For example, Mugny et al. (1975) found evidence that variation in prior knowledge among collaborating group members improved individual task performance. Hinsz et al. (1997, p.48) suggest that "research indicates more divergent representations increase the chances that the group will arrive at a useful solution" and that groups function effectively only when differences of opinion are made explicit and apparent.

Johnson and Johnson (1979) proposed a conflict resolution model in which controversy in interaction leads to *conceptual conflict* that encourages group members to resolve the conflict by seeking new information (epistemic curiosity) and negotiating to resolve conflicting opinions. In agreement with this model, some researchers suggest learning benefits if students present and defend their own diverse views and also challenge the views of others (e.g., Andriessen 2006; Jorczak and Bart 2009). Learning groups also tend to display *concurrence seeking* (Smith et al. 1984) in which the goal of group effort is seen as reaching agreement as soon as possible, with as little disagreement as possible. Concurrence seeking is a social process, which tends to minimize socio-cognitive conflict. Conceptual conflict as described by Johnson and Johnson (1979) is a social process that occurs among group members. Such socio-cognitive conflict must be distinguished from individual internal conflict between sensed information and stored knowledge. Socio-cognitive conflict requires more intentional effort to resolve the conflict and also requires acknowledgement and participation of other group members to resolve the conflict. To support the principle of learning benefits of socio-cognitive conflict, researchers have relied on (mainly descriptive) models of Piaget (e.g., see De Lisi and Goldbeck 1999) or other social psychology theories that do not reference basic memory functions or explain resolution of socio-cognitive conflict or social interaction in terms of the processing of information.

Convergence of knowledge

Knowledge representations of people working in teams tend to converge (Fischer and Mandl 2005). A knowledge convergence perspective asserts that the basis of individual learning is a convergence of group member knowledge resulting from collaborative learning activities. Convergence is seen as an iterative process in which individuals refine their mutual knowledge over time by interaction (Roschelle 1996). Roschelle (1980, 1996) asserts that convergence, not conflict, is the crucial aspect of collaborative learning. Fischer and Mandel (2005), however, found that convergence of factual knowledge could not be attributed to learner interaction, but that shared application-oriented knowledge is affected by peer interaction. The relationship of knowledge convergence to targeted or beneficial individual learning outcomes is an active area of CSCL research, but the knowledge convergence perspective is not fully developed, especially from an information processing perspective.

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Collaborative discussion models that link social to individual learning

When peer discussion is used to promote learning, the knowledge of group members is externalized and then processed by the group. To develop a comprehensive theory of learning by discussion, theorists must relate the process of collaborative social interaction to the cognitive processing of the individual. Stahl (2000) makes the point that CSCL theorists and researchers often do *not* make an explicit connection between social interaction and learning within the individual:

> Despite frequent references to constructivism in the CSCL literature, it is not clear in that literature which cognitive processes are involved in collaborative knowledge building. In particular, it continues to be unclear to skeptical readers of this literature what the relationship is of collaborative group processes to individual cognitive processes. (Stahl 2000. p. 71)

Stahl (2000) presents a model that attempts to clarify which internal and external processes are involved in group learning and, to a lesser extent, *how* these processes are involved. The Stahl (2000) model specifies that group learning is based on triggers—statements by group members that challenge the current understanding of other group members. A breakdown in a student's current understanding motivates the reorganization of mental representations and structures of that student (an internal process). When this breakdown in understanding occurs in a collaborative learning context, learners are said to construct new knowledge by processing information with the group (a social process). Stahl (2000) identifies clarification, negotiation, and formalization as the group processes used to achieve a convergence of new group knowledge that also results in individual understanding. Stahl (2000) explains learning by social interaction in this way:

> This happens when someone's personal belief is articulated in words and this public statement is taken up in a social setting and discussed from the multiple perspectives of several participants. The original statements are thereby articulated into a more refined and extensive discussion of the topic, subject to conflicting interpretations. The discussion consists of arguments providing rationales for different points of view. The interchange may gradually converge on a shared understanding resulting from a clarification of differences in interpretation and terminology. (p. 72).

Thus, the Stahl (2000) model supports the idea that social interaction, if diverse enough, triggers cognitive discomfort in an individual, who then uses convergent group processes in seeking a resolution to the discomfort. Ideally, the group, in processing diverse information, moves toward a mutual conclusion that satisfies all group members. Stahl's model is a step towards merging social and cognitive models, but it does not represent individual cognition and learning in terms similar to information processing models and does not clearly distinguish individual and social conceptual conflict processes.

Schellens and Valcke (2005) propose a model of collective learning that integrates social constructivist principles with the concepts of information processing. Processing is triggered and directed by tasks presented in the collaborative learning environment. These tasks require that learners express their knowledge in a way that is meaningful to other group members (i.e., they externalize information in a way thought to help the group). The group therefore provides both a richer environment (more information) and more processing capacity, as the cognitive resources of the group are greater than any individual member (Schellens and Valcke 2005). This model is unspecific about how groups process information using their greater processing capacity.

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These models of learning by peer discussion aim to establish a cognitive basis for social constructivist principles, thus supporting the long-held belief in the importance of social interaction for learning. In both models, social interaction stimulates individual learning. Ultimately, all models meant to represent learning by discussion must explain how group communication of information interacts with cognitive processing of individual group members and also explain how and why groups process information. The models of Stahl (2000) and Schellens and Valcke (2005) are important steps in creating a model of learning by social interaction, but neither is sufficient to guide CSCL research based on information processing models. Neither model addresses information divergence and convergence, nor considers the processing of information over a collaborative time period.

Collaborative information processing (CIP) model

During collaborative learning, information processing is partially externalized via social interaction among peers. Dynamic exchange of symbolic information enables groups to process externalized symbolic information. As group members work cooperatively to address learning tasks, they interactively exchange information for individual processing that exceeds what is present in course materials and personal experience. Group members communicate representations and potentially process those representations with internal cognitive processes as specified by information processing models.

Collaborating learners, however, also use *group* (socio-cognitive) processes that transform expressed information to influence group members and to meet group goals (often determined by the learning task). Interaction enables individuals to benefit from the processing of other group members. Group processes that are beneficial to learning, though recognized in much CSCL research, have not been described from an information processing perspective. The goal of the collaborative information processing model (CIP) is to describe social interaction for learning by means of information processing concepts and principles, and to describe the key processes by which groups transform information.

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Group information processing

Hinsz et al. (1997) reviewed research that takes an information processing view of group performance (not specifically collaborative learning). Hinsz et al. (1997) used an information processing model that does not reference basic memory functions such as working memory, but identifies information encoding, storage, and retrieval as key processes for individual processing and suggests that these processes are relevant to group information processing.

The processes of internalization and externalization are important for characterizing group information processing because these processes are the means by which information exchanged is processed by the individual group members and made available to the group. Individuals process information into knowledge and then express representations of their (perhaps new) knowledge. Thus all group level processing such as clarification, elaboration, and conceptual conflict resolution is accomplished via internalization and externalization.

Key group processes for learning

The individual processes of externalization and internalization describe how information flows to and from individual cognitive systems and a shared information pool of symbolic information (e.g., discourse, mutually-created graphics and documents). Externalized information can diverge and converge (represent different or similar knowledge) as group members try to meet group goals established by a collaborative learning task.

Divergent group processing Divergent information externalized by a group member can trigger the internalization of another group member. The key divergent process for learning in groups is similar to the key memory control process in individuals—elaboration. Externalized information available in groups diverges due to differences in students' knowledge and cognitive abilities (i.e., expressed group information is the result of more diverse elaborative rehearsal of group members).

The expression of divergent information in groups results in increased conceptual conflict within group members, which is the primary benefit of collaborative learning. Group processing is potentially superior to individual processing because group interaction provides greater opportunity for more divergent expressed representations (i.e., information is elaborated beyond what an individual could do). Information divergence and the resulting conceptual conflict is a necessary condition for collaborative learning to exhibit process gain. If group members merely agree to representations (without sufficient divergence and conflict) or ignore the representations of others, collaborative learning has no advantage over individualistic learning.

Convergent group processing Learners cognitively act to resolve internal conceptual conflict but also may intentionally attempt to resolve conceptual conflict among group members by social processes (e.g., Smith et al. 1984). Collaborating group members work to resolve conceptual conflict among group members by proposing and identifying representations thought to satisfy some or all group members. Ideally, students use social processes that make information more meaningful to group members, such as clarification and negotiation, to resolve conflict (Stahl 2000). Argumentation is also a social process that can clarify information and persuade group members to a mutual representation (e.g., Andriessen et al. 2003). Such processing can result in convergence of expressed information.

As a result of social processing to achieve group goals and resolve conceptual conflict, group members may adopt similar representations as solutions to learning tasks—*knowledge* converges. It is presumed that information expressed during interaction will also converge as knowledge converges. During such processing, group members decrease or narrow the information being considered as resolving the learning task. Information convergence is the result of *identification* and *selection* processes in which information obtained from resources (including members' experiences) is by argument suggested as relevant for resolving the learning task. The convergence of expressed information indicates an increasing probability that group members are adopting similar representations. Information convergence also explicitly identifies the resolution of the discussion task, thus externalizing and summarizing the effort of the group. The impetus for such convergence is the need to achieve group goals and a cooperative disposition (positive interdependence). Convergence is made possible by the greater information processing resources and knowledge base of the group and instructional aids, such as scripting or modeling.

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It is important to note that information convergence alone is insufficient to characterize group learning. Individual learning can occur due to increased information divergence whether or not expressed information (or group knowledge) converges. Rapid information convergence without sufficient preceding divergence will not result in group learning because group members have not experienced sufficient conflict to change their stored representations. Group information may also converge on incorrect information (e.g., misconceptions).

Phases of collaborative information processing

The Collaborative Information Processing (CIP) model posits that both timing and sequencing of group information processing are important for collaborative learning. Collaborative learning is an iterative process in which students repeatedly externalize information they think relevant to the learning task, internalize information from others, and re-externalize newly processed representations. The nature of the information expressed can change over time. Collaborative learning interactions have phases in which information diverges or converges.

Initially externalized information represents the current knowledge of each group member. Characteristics of this initial information are determined by factors such as group heterogeneity and the nature of the learning task. In the second phase, information diverges (increases in diversity) due to individual processing. To support learning that targets the achievement of specific learning objectives, a third phase is required in which expressed information converges via social processing.

Effective collaborative information processing can therefore be characterized by three phases. An *initial phase* of externalization of information that learners believe useful is followed by a *divergent phase* in which learners elaborate initial information, and then a *convergent phase* in which information is reduced to what is mutually accepted by the group. The divergent phase is sufficient for individual learning, but the specific learning that occurs is difficult to predict and varies among individual group members. Facilitators or scripts can act to increase divergence, for example by using scripts that guide academic controversy (e. g., Smith et al. 1984).

Achievement of specific learning outcomes is enhanced if expressed information converges on the target outcome. Students in collaborative environments sometimes merely agree with initially proposed information to quickly complete the assignment or because of concurrence seeking (Smith et al. 1984). Such premature convergence of information does not result in knowledge convergence or learning. The CIP model suggests that convergence is beneficial for learning only when convergence results from specific group information processes (e.g., selection and argumentation) due to conceptual conflict that follows a sufficiently divergent phase. The third phase can be supported by instructor action or scripts that model or direct convergence via, for example, argumentation (e.g., Andriessen et al. 2003).

Learning principles and methods derived from the CIP model

The CIP model explains and predicts multiple principles of collaborative learning. For example, the model explains why peer-to-peer collaboration can be more effective than student interaction with teachers or experts. Externalized representations from peers are more likely to activate stored representations because peer representations are more alike in

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terms of terminology, context, and complexity. The similarity of expressed representations is one basis for greater learning efficiency of collaborative learning as peer representations are more meaningful than representations from experts.

The CIP model predicts that heterogeneous groups will learn better than homogeneous groups. Though the model indicates that peers are more likely to communicate information effectively, CIP also indicates that students must be sufficiently heterogeneous in their knowledge to increase the probability that expressed information will diverge and conflict. Peer collaboration promotes learning by confronting learners with information that is similar to, yet inconsistent with, their stored representations. Collaborative learning environments offer greater potential for learning than individualistic learning environments because groups potentially offer greater divergence of information and therefore more conceptual conflict. Heterogeneous groups have a greater potential for expressing divergent information and therefore have a greater probability of generating conceptual conflict in members.

Some evidence suggests that divergence of information is beneficial for group outcomes such as group decision making (Hinsz et al. 1997; Schultz-Hardt et al. 2002). Generative statements in collaborative discussion are related to increased group conceptual conflict (Jorczak and Bart 2009), indicating that divergent processes are related to deeper processing for learning. The CIP model predicts that methods to increase expressed information divergence will promote learning in collaborative discussion. For example, open questions or discussion tasks that are controversial will result in better learning (e.g., Kirschner et al. 2008). Some methods used in collaborative learning, e.g., scripting (King 2007; O'Donnel 1999), may underemphasize divergent processing and instead focus on socio-cognitive processes that are primarily convergent such as negotiation and joint knowledge construction.

The CIP model also challenges some popular collaborative learning research concepts and principles. An information processing perspective indicates that knowledge, an internal construction, cannot be shared. Knowledge can only exist in a brain, but information representing that knowledge can exist outside the brain and can be shared. This view of knowledge is contrary to theoretical and research perspectives that seek to examine knowledge sharing or "co-construction". Conceptions of group knowledge construction must be defined in terms of information convergence expressed by co-constructers who do not share meaning but rather construct similar meaning based on expressed information. Weinberger et al. (2007, p. 417), for example, distinguish "equivalent" (similar) knowledge from "shared" (identical) knowledge. The word share, however, implies that the shared knowledge is co-located and can be accessed by either student. The meaning of information, however, is not shared as students are likely to diverge in their answers as the scope of questioning increases. The concept of shared knowledge—as opposed to shared information—confuses the theoretical conception of the collaborative learning process.

Studies of collaborative learning tend to focus on convergent rather than divergent processes. The CIP model questions, however, the idea that information convergence alone is beneficial for learning. Students in collaborative environments sometimes merely agree with initially proposed information to quickly complete the assignment. Such premature convergence of information does not indicate learning or even knowledge convergence. CIP suggests that convergence is beneficial for learning only when convergence results from specific group information processes (e.g., selection and argumentation) due to conceptual conflict among group members. It is the processing itself that results in better internal and external representations within individuals, not the adoption of similar knowledge by group

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members. Fischer and Mandl (2005) allow that studies of group decision-making show that converging cognitive processes do not necessarily result in similar outcomes or better individual learning. Fischer and Mandl (2005) found that most knowledge acquired during a highly convergent process was not shared (not externalized). This finding is consistent with the idea that convergent processes alone do not lead to targeted learning and that group members primarily learn different knowledge during collaborative learning due to divergent rather than convergent processing.

Hinsz et al. (1997) remark that some researchers claim that group members narrow their perspectives due to social interaction; other researchers claim that groups hold a more complex perspective. The CIP model suggests that divergent processes, indicated by divergent expressed information, are necessary and sufficient for collaborative learning. Information divergence, therefore, should be the primary goal of all collaborative learning interventions. Converging information can indicate achievement of some types of learning goals, but only after sufficient divergence. Techniques used with collaborative learning, such as scripting and shaping, must aim primarily to increase divergence.

Modeling, a key process for some non-IP theoretical perspectives of learning by social interaction (e.g., De Lisi and Goldbeck 1999; Hogan and Tudge 1999), explains learning via social interaction in which less knowledgeable group members gain knowledge from more knowledgeable members. The modeling process does not explain how students of equal ability can benefit from collaboration or how a student with greater knowledge can learn from collaboration with a less knowledgeable student (as demonstrated e.g., by Mugny et al. 1975). Modeling is consistent with a convergence of expressed information as students with lesser knowledge adopt the information or procedures expressed by group members with greater knowledge. Learning via divergent processes, however, does not require that knowledge be obtained from group members with more knowledge. More knowledgeable group members can also learn, as can members with similar knowledge levels.

A CIP perspective indicates that divergence/convergence of information externalized during collaborative learning is a key aspect of message content. Other aspects of message content may also be important; for example, Weinberger et al. (2007) describe transactivity as important in analyzing collaborative interaction for learning. Transactivity is how and how strongly group members refer to (i.e., process information from) externalizations provided by other group members (for consensus building, a convergent process). Such aspects of externalized information can productively be analyzed from an information processing perspective. Other factors such as *how* information diverges or converges, or the type of information expressed, may affect processing and learning.

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Summary

While the principles about the utility or necessity of social interaction for learning are ubiquitous, explanatory theory is less so. Why is social interaction preferred or required for learning? Any theory purporting to explain why social interaction is effective for learning must align with established theories of individual memory and learning. An information processing view has been proven to be an extremely useful perspective that, when applied to social interaction and collaborative learning, results in specific testable principles that can guide effective research and suggest practical ways to implement better collaborative leaning environments. Just as an information processing view can explain aspects of individual cognition and learning, an information processing perspective of social

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interaction can offer more foundational and explanatory models of social interaction for learning.

Groups are information processors with a very limited scope and function. The only mutual memory of a group is the information the group externalizes. Social processing is limited to what group members do to the externalized information—so group "cognition" is very limited compared to individual processing done by humans or computers with extensive knowledge stores. Information processed by a group, however, is very valuable as a stimulant and guide for individual cognitive processing and learning.

The CIP model of learning through social interaction emphasizes individual processes of internalization and externalization as the basis of group information processing. Viewing collaborative learning from an information processing perspective enables theorists to connect learning via social interaction with established models that explain individual learning. Individual processing can cause information to diverge, which increases conceptual conflict within and among group members resulting in improved learning. Social processing can cause converging information to reduce conflict among members and achieve group consensus, perhaps resulting in convergent knowledge. The CIP model presented here should be regarded as an initial and non-comprehensive effort to view collaborative learning as the result of individual and social information processing. Future directions would be to identify methods that increase information divergence in groups and also methods that cause information to converge to targeted learning outcomes after sufficient divergence is achieved. (Much research is already pursuing such methods although perhaps based on infirm theoretical grounds). Cognitive architectures that model individual cognition and learning can be expanded to model interaction and guide research about social processing of information.

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References

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Anderson, T., Howe, C., Soden, R., Halliday, J., & Low, J. (2001). Peer interaction and the learning of critical thinking skills in further education students. *Instructional Science, 29*, 1–32.

Andriessen, J. (2006). Collaboration in computer conferencing. In A. M. O'Donnel, C. E. Hmelo-Silver, & G. Erkens (Eds.), *Collaborative learning, reasoning, and technology*. Mahwah: Lawrence Erlbaum Associates.

Andriessen, J., Baker, M. J., & Suthers, D. (2003). Argumentation, computer support, and the educational context of confronting cognitions. In J. Andriessen, M. J. Baker, & D. Suthers (Eds.), *Arguing to Learn: Confronting cognitions in computer-supported collaborative learning environments* (pp. 1–25). Dordrecht: Kluwer Academic Publishers.

Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation: Advances in research and theory, Vol. 2* (pp. 89–195). New York: Academic.

Buchs, C., Butera, F., Mugny, G., & Darnon, C. (2004). Conflict elaborations and cognitive outcomes. *Theory Into Practice, 41*(1), 23–30.

Craik, F. I. M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior, 11*, 671–684.

Craik, F. I. M., & Watkins, M. J. (1973). The role of rehearsal in short-term memory. *Journal of Verbal Learning and Verbal Behavior, 12*(6), 599–607.

Cress, U., & Kimmerle, J. (2008). A systemic and cognitive view on collaborative knowledge building with wikis. *International Journal of Computer Supported Collaborative Learning, 3*(2), 105–122.

De Lisi, R., & Goldbeck, S. L. (1999). Implications of Piagetian theory for peer learning. In A. M. O'Donnell & A. King (Eds.), *Cognitive perspectives on peer learning*. Mahwah: Lawrence Erlbaum Associates.

De Wever, B., Schellens, T., Valcke, M., & Van Keer, H. (2006). Content analysis schemes to analyze transcripts of online asynchronous discussion groups: A review. *Computers and Education, 46*, 6–28.

EDITOR'S PROOF JrnlID 11412_ArtID 9104_Proof# 1 - 14/12/2010

Fischer, F., & Mandl, H. (2005). Knowledge convergence in computer-supported collaborative learning: The role of external representation tools. *The Journal of the Learning Sciences, 14*(3), 405–441.
Garrison, D. R., Anderson, T., & Archer, W. (2001). Critical thinking, cognitive presence, and computer conferencing in distance education. *American Journal of Distance Education, 15*, 7–23.
Gokhale, A. A. (1995). Collaborative learning enhances critical thinking. *Journal of Technology Education*, *7*(1). Q7
Hammond, M. (2005). A review of recent papers on online discussion in teaching and learning in higher education. *Journal of Asynchronous Learning Networks*, *9*(3).
Hinsz, D. A., Tindale, R. S., & Vollrath, D. A. (1997). The emerging conceptualization of groups as information processors. *Psychological Bulletin, 121*(1), 43–64.
Hogan, D. M., & Tudge, J. R. H. (1999). Implications of Vygotsky's theory for peer learning. In A. M. O'Donnell & A. King (Eds.), *Cognitive perspectives on peer learning*. Mahwah: Lawrence Erlbaum Associates.
Johnson, D. W., & Johnson, R. T. (1979). Conflict in the classroom: Controversy and learning. *Review of Educational Research, 49*(1), 51–69.
Johnson, D. W., & Johnson, R. T. (1994). An overview of cooperative learning. In J. Thousand, A. Villa, & A. Nevin (Eds.), *Creativity and collaborative learning*. Baltimore: Brookes Press.
Johnson, D. W., Maruyama, G., Johnson, R., Nelson, D., & Skon, L. (1981). Effects of cooperative, competitive, and individual goal structures on achievement: A meta-analysis. *Psychological Bulletin, 89*, 47–62.
Johnson, D. W., Johnson, R. T., & Smith, K. A. (1998). *Active learning: Cooperation in the college classroom*. Edina: Interaction Book Company.
Jorczak, R. L., & Bart, W. (2009). The effect of task characteristics on conceptual conflict and information processing in online discussion. *Computers In Human Behavior, 25*(5), 1165–1171.
King, A. (2007). Scripting collaborative learning processes: A cognitive perspective. In F. Fischer, I. Kollar, H. Mandl, & J. M. Haake (Eds.), *Scripting computer-supported collaborative learning* (pp. 13–38). New York: Springer Science + Business Media.
Kirschner, P. A., Beers, P. J., Boshuizen, H. P. A., & Gijselaers, W. H. (2008). Coercing shared knowledge in collaborative learning environments. *Computers in Human Behavior, 24*, 403–420.
Langley, P., Laird, J. E., & Rogers, S. (2009). Cognitive architectures: Research issues and challenges. Retrieved from http://cll.stanford.edu/~langley/papers/final.arch.pdf.
Lave, J. (1987). *Cognition in practice*. New York: Cambridge University Press.
Lowery, N., & Johnson, D. W. (1981). Effects of controversy on epistemic curiosity, achievement, and attitudes. *Journal of Social Psychology, 115*(1), 31–43.
Mayer, R. E. (1996). Learners as information processors: Legacies and limitations of educational psychology's second metaphor. *Educational Psychologist, 31*(3/4), 151–161.
Meyer, K. A. (2003). Face-to-face versus threaded discussions: The role of time and higher-order thinking. *Journal of Asynchronous Learning Networks*, 7(3).
Mugny, G., Doise, W., & Perret-Clermont, A. N. (1975). Social interaction and the development of cognitive operations. *European Journal of Social Psychology, 5*(3), 367–383.
Newell, A. (1990). *Unified theories of cognition*. Upper Saddle River: Harvard University Press.
Newell, A., & Simon, H. A. (1976). Computer science as empirical inquiry: Symbols and search, Communications of the ACM, 19
O'Donnel, A. M. (1999). Structuring dyadic interaction through scripted interaction. In A. M. O'Donnell & A. King (Eds.), *Cognitive perspectives on peer learning*. Mahwah: Lawrence Erlbaum Associates.
Ormrod, J. E. (2004). *Human learning* (4th ed.). Upper Saddle River: Merrill Prentice Hall.
Pinker, S. (1997). *How the mind works*. New York: W. W. Norton & Company.
Raaijmakers, J. G. W. (1993). The story of the two-store model: Past criticisms, current status, and future directions. In D. E. Meyer & S. Kornblum (Eds.), *Attention and Performance XIV: Synergies in Experimental Psychology, Artificial Intelligence, and Cognitive Neuroscience* (pp. 467–488). Cambridge: MIT Press.
Raaijmakers, J. G. W., & Shiffrin, R. M. (2004). Models of memory. In H. Pashler & D. Medin (Eds.), *Stevens' handbook of experimental psychology, third edition, volume 2: Memory and cognitive processes*. New York: Wiley.
Roschelle, J. (1980). Learning by collaborating: Convergent conceptual change. *The Journal of the Learning Sciences, 2*(3), 235–276.
Roschelle, J. (1996). Learning by collaborating: Convergent conceptual change. In T. Koschmann (Ed.), *CSCL: Theory and practice of an emerging paradigm* (pp. 209–248). Mahwah: Lawrence Erlbaum Associates.
Schultz-Hardt, S., Jochims, M., & Frey, D. (2002). Productive conflict in group decision making: Genuine and contrived dissent as strategies to counteract biased information seeking. *Organizational Behavior & Human Decision Processes, 88*(2), 563–586.

UNCORRECTED PROOF

Schellens, T., & Valcke, M. (2005). Collaborative learning in asynchronous discussion groups: What about the impact on cognitive processing? *Computers in Human Behavior, 21*, 957–975.

Slavin, R. (1980). Cooperative learning. *Review of Educational Research, 50*, 315–342.

Slavin, R. E. (1987). Developmental and motivation perspectives on cooperative learning: A reconciliation. *Child Development, 58*, 1161–1167.

Slavin, R. E. (1992). When and why does cooperative learning increase achievement? Theoretical and empirical perspectives. In R. Hertz-Lazarowitz & N. Miller (Eds.), *Interaction in cooperative groups* (pp. 145–173). New York: Cambridge University Press.

Slavin, R. E. (1996). Research on cooperative learning and achievement: What we know and what we don't know. *Contemporary Educational Psychology, 21*, 43–69.

Slavin, R. E., & Tanner, A. M. (1979). Effects of cooperative reward structures and individual accountability on productivity and learning. *Journal of Educational Research, 72*(5), 294–298.

Smith, K., Johnson, D. W., & Johnson, R. T. (1984). Effects of controversy on learning in cooperative groups. *Journal of Social Psychology, 122*, 199–209.

Stahl, G. (2000). A model of collaborative knowledge-building, In Proceedings of the Fourth International Conference of the Learning Sciences (ICLS 2000), (pp. 70–77). Ann Arbor, MI. Retrieved on November, 2010 from http://GerryStahl.net/cscl/papers/ch14.pdf.

Sweller, J., Kirchner, P. A., & Clark, R. E. (2007). Why minimally guided teaching techniques do not work: A reply to commentaries. *Educational Psychologist, 42*(2), 115–121.

Tennyson, R. D., & Breuer, K. (1997). Psychological foundations for instructional design theory. In R. D. Tennyson, F. Schott, N. Seel, & S. Dijkstra (Eds.), *Instructional design: International perspective, volume 1: Theory, research, and models*. Mahwah: Lawrence Erlbaum Associates.

Vygotsky, L. (1978). *Mind in Society: The development of higher psychological processes*. Cambridge: Harvard University.

Vygotsky, L. (1986). *Thought and language*. Cambridge: Harvard University. MIT press: Cambridge, Q8 Massachusetts.

Webb, N. M. (1989). Peer interaction and learning in small groups. *International Journal of Educational Research, 13*, 21–39.

Weinberger, A., Stegmann, K., & Fischer, F. (2007). Knowledge convergence in collaborative learning: Concepts and assessment. *Learning and Instruction, 17*, 416–426.

Whitney, P. (1987). Psychological theories of elaborative inferences: Implications for schema-theoretic views of comprehension. *Reading Research Quarterly, 22*(3), 299–310.

Wiley, J., & Bailey, J. (2006). Effect of collaboration and argumentation on learning from web pages. In J. Andriessen, M. J. Baker, & D. Suthers (Eds.), *Arguing to learn: Confronting cognitions in computer-supported collaborative learning environments* (pp. 297–321). Dordrecht: Kluwer Academic Publishers.

Yeager, S., Johnson, D. W., & Johnson, R. T. (1985). Oral discussion, group-to-individual transfer, and achievement in cooperative learning groups. *Journal of Educational Psychology, 77*(1), 60–66.

UNCORRECTED PROOF