A Survey of Literature on Computerized Notational Tools and Their Ability to Support Online Co-Constructive Meaning-Making

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Abstract

Providing online asynchronous courses to participants is more difficult than digitizing the classroom and presenting the same material on the Web. Instructors need to provide motivational and knowledge building experiences which can be harder to deliver at a distance than in a face-to-face environment. The field of computer-supported collaborative learning seeks to provide opportunities where learning in groups (at a distance or face-to-face) can be enhanced by technological tools. We review the definition of computer-supported collaborative learning and common research methodologies and theories used. We also analyze several notations used to support co-constructive meaning making. Co-constructive meaning-making is where participants create new knowledge through interactions. Notations that support co-construction can be used to provide motivational and knowledge building experiences in asynchronous, online learning environments.

1 Introduction

Since the advent of the Internet and the World Wide Web, many people have designed ways to take advantage of the unique communication qualities that this technology affords. Not only are educators using the advances in technology to provide online courses, but also to enrich face-to-face (FTF) interactions. Online courses are beneficial to both institutions and students. Institutions can provide instruction to more students by providing online courses, and students take courses at a distance and at times that are more convenient for them. Today, many full-time workers can further their education by taking online courses at night or when it works best for them.

However, there tends to be a misconception that instructors only need to digitize their classroom and send it to an unlimited number of students via the Internet without any further effort being required. Although these materials may provide a valuable resource for the students, videos, computerized models, and other digitized resources are just ways to deliver information. Learning is more than information delivery. The bandwidth of information has increased, but it still does not provide the student any additional motivation, resources for the student clear up confusion, or ensure that the knew knowledge will be remembered and placed in the correct context. Providing motivational and interactional resources to the student is usually more difficult at a distance than it is in a FTF setting.

One way to provide motivational and interactional resources is to have students collaborate in a mutually beneficial manner. The field of Computer-Supported Collaborative Learning (CSCL) is dedicated to finding ways to improve technology-oriented instruction through collaboration. This includes online instruction at a distance, and FTF instruction that involves technology. Notations are tools through which students can interact and represent their state of knowledge and understanding, and can include mostly textual notations, like discussion forums and wikipages, and graphical notations, like concept maps and matrices. In this chapter, we review CSCL and similar fields and then examine notations and their ability to support co-constructive meaning-making.

Co-constructive meaning-making is where, through interacting with other learners or participants, one can build new knowledge (knowledge that is new to the individual). The new knowledge can be built through an argumentative process, a peer-review process, or several other ways. If such is to be done in an online asynchronous environment, the notations with which participants express their ideas need to support and encourage co-construction. By encouraging co-construction, participants can receive the motivation and learning experiences that lead to knowledge gain.

We will proceed as follows. First we will review the definition of CSCL along with the methodologies and experimental paradigms used in the field. We will then overview the theory on how computer tools support collaborative learning. After, we will review the literature about several notations. We will finish with overviewing some of the challenges current notations have in supporting co-constructive meaning-making and present solutions in the literature and our own solutions.

2 Computer-Supported Collaborative Learning

In this section we will overview Computer-Supported Collaborative Learning (CSCL). We will first cover the definition of Computer-Supported Collaborative Learning which also includes the epistemologies used in the field. We also talk about the role that computers and other technology play in the field and review several different research methodologies.

2.1 Definition of Computer-Supported Collaborative Learning

Although there still is some disagreement over what constitutes CSCL (10), we present a generalized definition to which most work in CSCL conforms. We also point to the areas where researchers differ on their definition. The definition of CSCL is usually presented by defining each concept that the field integrates (25): computer-supported, collaboration, and learning. In the following sections, we review the definition of each concept.

2.1.1 Learning

Since the the main goal of work done in CSCL is to improve learning, it is important to define exactly what is meant by learning. In CSCL, there is a broad spectrum of what is considered learning and not all researchers agree on a single definition. In its simplest and broadest definition, "'learning something' may be interpreted as 'follow a course,' 'study course material', 'perform learning activities such as problem solving,' 'learn from lifelong practice,' etc." (10). In many instances, learning is thought of as knowledge transfer, either from a teacher to student, or from a book to a student. Most research using this definition, or a knowledge-communication epistemology, focuses on how to support the acquisition of knowledge or how to improve the presentation and communication of knowledge. However, most researchers in CSCL have moved away from a knowledge transfer definition of learning to a constructivist or interactional view of learning (62).

In a constructivist epistemology, knowledge is constructed by the learner's efforts at meaning making (62). Constructivism focuses on the processes the individual undertakes to learn. Sticking to the constructivist definition of learning, collaboration is thought of as a catalyst in the meaning-making processes but is not intrinsic to the learning itself. In other words, collaboration may help an individual explore more ideas, however an individual can construct knowledge through self-talk as he examines his experiences. Traditionally, philosophers' viewed learning as being an individual process not available to direct inspection. However, contemporary philosophy has placed learning in the meaning negotiations carried out in the social world (53). In CSCL, constructivism takes the form of "collaborative knowledge construction" (52), which moves towards an interactional epistemology.

In an interactional epistemology, used by many CSCL authors, collaboration is not a catalyst for learning, but is necessary to it. This also brings the agent of learning from the individual to the group (62). Researchers following this epistemology seek to discover how learning is produced within interactions (53). Instead of a unidirectional transfer of knowledge, it attributes learning to group interactions. However, "it does not explain how knowledge that does not predate the communication is jointly constructed within the communication process." (62). Intersubjective epistemologies take this a step further by specifying that the meaning-making process is constituted of social interactions and that "interpretations can be jointly created through interaction in addition to be formed by individuals before they are offered to the group" (62). Knowledge building (47; 48) also uses an intersubjective approach, but distinguishes itself by specifying that the knowledge building must be done intentionally on the community level, meaning it is an effort that the community intentionally does to increase its knowledge.

Researchers still know relatively little in terms of the memory process, but it has been shown that our brain works to organize knowledge in hierarchical frameworks and that we more easily remember facts when we can place them within some previously learned context (3). Through tutoring, discussions, and other activities, collaboration in groups can help participants associated new knowledge in a previously learned context.

There are a wide variety of definitions and approaches to investigate learning. Most work done in CSCL focuses on either collaborative knowledge construction, interactional learning, or intersubjective meaning-making. For this work, we will focus on these epistemologies and will only distinguish between them when necessary.

2.1.2 Computer-Supported

In CSCL, computer-supported refers to any computing technology used to aid in the learning process. Most often it is a computer, but it can also include mobile devices such as phones, PDA's, touch tablets, and music players. Since the advent of the Internet, most research is done with multiple computers or devices connected through the Internet. However, stand-alone desktop software and other non-Internet based technologies are still studied and are considered the computer-supported aspect of CSCL research (53).

There is often a confusion between CSCL and e-learning. E-learning is often motivated by a belief that one can digitize classroom content and distributing it over the Internet to a large number of students without any further involvement of instructors or other costs. Although these digitized resources may provide important study aids for the students, in order to be effective there has to be a larger motivational and interactive presence (53; 62). Thus, in CSCL, there is a much greater emphasis on how the technology can support collaborative knowledge construction, and less of an emphasis on technological advances in digitizing and presenting material over the Internet. In fact, in CSCL research, the participants can be communicating in a FTF environment while interacting with artifacts on a computer, or even while searching the Internet for information. "Computer support can take the form of distant or [FTF] interaction, either synchronously or asynchronously." (53).

There is some disagreement in the degree that technology must play a role to be considered CSCL research. Some researchers believe that by studying the meaning-making process without technological augmentation can still be considered research in CSCL (32), whereas other researchers insist that technology play a role in CSCL research by stating that technology be the set of tools that afford meaning making (25). Also, using technology has an advantage because of its ability to log and replay interactions made during the meaning-making process. This allows researchers to observe interactions on various scales.

2.1.3 Collaboration

There is a distinction between collaboration and cooperation. With cooperation, participants can take a task and divide it into subtasks. Each participant is then assigned a subtask to complete individually. Then the participants meet together to piece together their individual parts to complete the task. In collaboration, individuals do the work together (10). Although there might be some spontaneous division of work between members (one member might focus on the details while the other member focuses on the bigger picture) this is still considered collaborative work. When the division of labor is 'horizontal' (or oriented on the same task) the work is considered collaborative, as opposed to a 'vertical' division of labor where partners work on different tasks (10). In collaboration, the group interactions like negotiation and sharing are where the learning takes place (53).

In CSCL, the size of the group can vary from dyads to societies. Most often, research is done with small groups because the data produced is smaller and easier to analyze. However, several studies also focus on larger scales, including the institutional or meso-level (25), and the communities level (27).

2.1.4 Networked Learning: An Alternative Approach

In general, networked learning (19; 54) distinguishes itself from Computer-Supported Collaborative Learning by the number of participants and possibly by the length of the participation. In CSCL groups are often small and the groups are associated through a course. In networked learning, communities come together for help and collaboration, but there is not an associated course. Networked learning uses many of the same notations and tools that CSCL does.

There are many Web sites that can be used to support networked learning. Wikipages (like Wikipedia.org), blogs, and social media are all tools that can be used by the community to collaborate and increase the community knowledge. Question and answer sites (like stackoverflow.com) can be a powerful tool to build community knowledge because they have a reputation system that encourages participation.

2.2 Research Methodologies used in CSCL

In this section we overview the research methodologies used in CSCL. Research in CSCL includes both analysis and design components. In the analysis component, researchers do not seek to reform goals, but seek to discover how participants are interacting during the meaning-making process. The design phase is prescriptive in nature, and tries to reform the habitats and practices of the participants to improve the meaning making process. The design and analysis components have a symbiotic relationship, where the analysis provides insight into designing new artifacts, and the new artifacts provide for more cases for analysis (53). Three different methodologies researchers use to conduct CSCL research include: an experimental paradigm, iterative design, and interactional analysis. In this section we review these methodologies.

2.2.1 Experimental Paradigm

In an experimental design methodology (57; 68), one compares an intervention to a control condition in terms of one or more variables. Using this paradigm, researchers usually analyze the data by coding the observed interactions and counting. Through statistical methods, the coded data is analyzed to draw general conclusions about the effects of the intervention when compared to the control group (62).

This methodology is useful because it compares the interventions group to a control group to determine the effects of the intervention, and it is a common methodology in most scientific fields. However, the coding and analysis phase of this approach, "[does not] directly analyze the accomplishment [of individual contributions]. Such an analysis must examine the structure of specific cases of interaction rather than categorize and aggregate single contributions" (62). Another weakness in this approach is that the results have weak validity in situations other than the specific example used in the experiment (62).

2.2.2 Iterative Design

Iterative design is a common methodology in the Human and Computer Interactions research field. Design-based research (1), where researchers are continuously creating, using, and studying different designs, and quisitive research (16), where researchers mix qualitative and quantitative methods, are both examples of iterative design methodologies. In this methodology, researchers design new interfaces, and then run several studies with human users to see how they use the new interface. Gathering feedback from users and stakeholders, researchers continuously improve the design of the artifacts and then retest the artifact. Exploring the design space is an important component of CSCL research strategies because CSCL is “trying to uncover the potential affordances of information technologies, so [they] need to explore the entire space of possible designs, pushing into new areas and identifying promising features” (62).

Although CSCL research requires iterative design to to explore new features, this methodology lacks a method to predict the results of the new features introduced in the interface (62). Without this guidance, it is hard for researchers to explain their results and direct new designs in the most promising directions.

2.2.3 Descriptive Analysis

To address the weaknesses of iterative design, researchers can turn to descriptive analysis, which includes conversational analysis (45), interactional analysis (26), and narrative analysis (20). With these methodologies, videos or transcripts are analyzed to find instances of where learning does occur between the participants. With conversational analysis, researchers micro-analyze short segments of the conversation, whereas narrative analysis looks for broader patterns.

One emerging form of analysis of interactions in collaborative environments is by finding and analyzing instances of “uptake”, which is where one participant takes up another participants contribution to create a new contribution. By creating uptake graphs (acyclic directed graphs) researchers can visualize the interactions, and then apply several different interpretations on the interactions. Several different theories can be applied to the the graph in order to determine how the affordances of the communication media influenced the learning process (62; 61).

These methodologies are well suited for making existentially quantified claims, such as a certain group sometimes engages in a certain behavior. However this isn’t sufficient to prove that certain affordances has an effect on practice. Experimental methodologies are much better suited to prove effectual conclusions.

Thus, in CSCL, researchers should take a hybrid approach, using several different methodologies at different stages of their work. Researchers can look for similar patterns in other transcripts and studies, and also identify where learning is absent. From this analysis, researchers begin to identify conditions that support collaborative learning and then design tools to guide participants into these conditions. Experimental studies can be employed to verify that a specific software feature promotes a better collaborative learning practices.

3 Theory on How Computer Tools Support Collaborative Learning

In this section we describe the theory on how computer tools support and guide participants in the collaborative learning process. We first define the role in which the CSCL field uses computers tools in collaborative learning. Next, we discuss how a computer tool's affordances can direct and guide individuals and finish by discussing how we analyze affordances in a group setting.

In the literature, researchers have a varied perspective on the role that computer tools play during collaboration. In one extreme, computer tools are considered a communication media that tries to recreate FTF interactions between participants. Most of the research produced with this perspective focuses on how the computer tools compare to FTF interactions. Researcher try to increase the bandwidth and multimodality of computer mediated communication (CMC) tools in order to reproduce FTF communication at a distance. Although progress can be made in this area, the ultimate goal of recreating FTF interactions at a distance may not be achievable. Differing timezones and cultures can have an effect on video meetings, and it has been shown that it is harder to establish trust without meeting face-to-face (43). Although FTF interactions have great value, CSCL seeks to take advantage of the unique affordances (discussed below) that CMC provides to improve learning in FTF and distance learning. CSCL research seeks to go beyond FTF learning and "rather than leaving efficient learning up to the learners, CSCL has an obligation to design technology that supports [and guides participants towards] effective collaborative learning" (62).

On the opposite extreme, computer tools are seen as an intelligent tutoring agent. In this extreme, computer tools replace the instructor by leading the student through a series of exercises that will hopefully produce new knowledge within the student. Researchers in this field includes Artificial Intelligence algorithms that can adjust the tutoring system to different conceptual models that various students might have. However, many of these systems focus on memorization of facts, and not on the elicitation of new knowledge. This is still an active field of research, but tends to focus on a learning model where the students learn mostly through information delivery (53).

There has been a paradigm shift towards the CSCL field, where researchers use collaborating groups to elicit new knowledge amongst participants (31). In CSCL, researchers focus on an area in between the two extremes. Researchers in CSCL see technological tools as more than just a communication medium but less than an intelligent tutoring system. These tools have certain affordances that can constrain and guide participants to use more productive means to co-construct knowledge. Although limiting the options available to learners "sounds negative, it is sometimes a useful strategy for two major reasons: reducing the socio-cognitive load and implementing a learning agenda" (62).

3.1 Affordances for Individuals

In this section we discuss work done to analyze user interfaces and their affordances. The work reviewed in this section is not specifically related to learning. In the next section we will discuss affordances in group settings. Affordances are properties of the world that make an action possible for things that can act (15; 14), for example a door handle allows people to open a door and also implies that you pull the door open. On the other hand, a bar implies that you push the door open. When applied to technology, perceptions can instruct users on how to use technological tools. Affordances can be perceived and hidden, and some hidden affordances can be perceived through experimentation, whereas other become apparent after acting on another affordance (14). Some affordances cannot only allow but also influence users into more productive work flows, whereas other might slow down or limit the user's ability to accomplish work.

For example, badly designed systems force the users into work flows that are either too restrictive or not used. Other bad designs don't provide the relevant information when needed. Cognitive dimensions is a set of discussion tools for designers (and people evaluating design) that allow them to detect areas that make it more challenging for users to do productive work (2). When designing or analyzing a notational system, one should consider several different dimensions including the following:

- Viscosity, or the resistance to change, measures how easily users can make changes to a notation.
- Visibility measures how much information is visible to the users during key iterations.
- Error-proneness is where the notational system invites mistakes and gives little protection to the user.

Utilizing these cognitive dimensions can serve as a base for researchers that strive to understand and improve notational systems for both individual and collaborative learning.

An example of applying cognitive dimensions when analyzing notations includes comparing sentential representations (textual representations) to diagrammatic representations. Diagrammatic representations include information that can be indexed in a plane, whereas sentential representations are indexed sequentially. By using diagrammatic representations, one can make explicit certain information that can only be implicit in sentential representations. Thus, actions like searching and determining the next step in a problem can greatly aided by using a diagrammatic representation (33).

When studying notations commonly used in geometric theorem proving, researchers discovered that the traditional method of writing a step-by-step proof gave little aid to students trying to determine the next step in the proof. By designing a more graphical interface that included information needed in proving the next step, the interface is capable at instructing students. "This implicit instruction comes both in the form of the notations used in the computer interface and also in the actions allowed by the interface" (29). From this and other work, we can conclude that notational systems can be designed not only as a method of notation, but also as a implicit guide to encourage users into better work flows, or when applied to learning, better ways to create new knowledge.

3.2 Group Processes

The previous section focuses on interactions between individuals and technology. In this section we focus on how technology can be used in group settings, but not necessarily pertaining to learning in group settings. When analyzing group work, productivity is a key measure on how well the group functions. Productivity is usually measured by comparing a group's productivity to the ideal theoretical productivity of the group. Several factors affect group productivity and include group heterogeneity, group size, group duration, group cohesion (9), group unity (70), and the task to be solved (55).

Losses in production can be caused by several factors. One factor is blocking (42), and occurs when a participant cannot perform his task because he is required to accomplish other tasks at the same time. An example of blocking is when a participant cannot think because he is required to listen to another group member instead. Asynchronous environments help participants overcome blocking by allowing time to think before responding. Another factor is evaluation apprehension (8), where a participant does not contribute to the group process because he fears being criticized. Free-riding (9) is where a participant does not participate and depends on others to do his part.

When applied to learning, these losses of production have an effect on the learning effectiveness. Evaluation apprehension and free-riding could prevent learners from fully participating in the learning process. In face-to-face meetings blocking could prevent some participants from participating. Online asynchronous environments could both reduce and increase these affects. Asynchronous environments give students the time to read responses and then formulate their own response. Online classes also increase anonymity which could encourage participants to post, but also encourages free-riding.

When designing collaborative system, one has to remember that an individual's attention is a scarce resource. Collaborating with a group through the use of technologies can require a high cognitive load. The participant needs to learn how to use the tools and interact with notations and other participants. Groupware should be designed to reduce cognitive load as much as possible (41).

3.3 Affordances for Collaborative Learning

3.3.1 Representational Guidance

Limiting what the participants can do, although negative sounding, is good because of it reduces cognitive load, and it can implement a learning agenda. It guides participants to interact in a way that is conducive to learning. (62). By constraining possible interactions, limiting available information, and controlling the salience of items in the notational tool being used, researchers can guide the participants to interact with the notational tool and other participants in ways that are more conducive to co-constructive learning (60).

Cognitive load can be reduced by having the appropriate information available and easily editable for the task at hand. For example, if participants are analyzing relationship between elements, the relationship should be easily visible and editable. By choosing and developing notational tools that naturally support the learning process, reduce cognitive load, and completing the task at hand, improvements in learning is demonstrated (58).

3.3.2 Alternatives to Representational Guidance

Besides using representational guidance, practitioners can also use scripting (69) to encourage more co-constriction. With scripting, participants receive learning objectives, types of activities, a specific role, and types of representations to use to facilitate collaborative learning (30). However, scripting can disturb the natural problem solving process, interfere with the dynamics of goal achievement, and increase cognitive load (11). Although, definitely an avenue for research, constructing notational tools with an appropriate use of representational guidance is a more natural process.

4 Assessment of Notational Tools

In this section we review the current and most widely used notational tools and discuss their advantages and disadvantages in terms on supporting co-constructive meaning-making. Previously, we have reviewed the field of CSCL and reviewed the research methodologies used in the field. We have also reviewed the theory on how computer tools support collaborative learning. In this section we discuss how specific tools support co-constructive meaning-making.

4.1 Discussion Threads

We now start our focus on specific notational tools, starting with discussion threads. Discussion threads are one of the most popular form of online collaboration. One participant can post a new topic, and other participants can reply to the thread. Replies can also receive replies. Threaded discussion can be found on many websites including blogs, news sites, social media sites, and any other site that provides a mechanism for discussion. They are also found in most learning management systems (LMS). Since threaded discussions are popular there is a wide body of literature pertaining to them. We focus on the literature that pertains to co-constructiveness.

Threaded discussions allow participants to take time for reflection without worrying about turn taking and other interactions that could increase cognitive load. Because threaded discussion are familiar with most participants, there is no need to teach participants how to use the tool. These advantages have helped threaded discussions because a common feature in LMS's (21).

The main disadvantage of threaded discussion is a lack of support for convergent processes (21). Because replies can only be attached to one message, participants rarely converge multiple messages together. The lack of this activity can slow participants seeking co-constructive meaning making. Studies suggest that threaded discussions create a tunnel effect that causes participants to focus on a few topics instead of the discussion as a whole (21). Also, the use of the unread count and other factors cause participants to have habitual practices that lead cause some discussions to end prematurely (22).

Threaded discussion can end prematurely because participants often practice a single pass strategy to online discussions: they login, review unread topics, and post new comments in reply to the unread topics. Topics that might be more difficult or require more effort tend to get ignored. This practice does not support co-constructive meaning-making because participants rarely perform summarizing or converging tasks (23).

Threaded discussion fail to support co-constructive meaning making because they do not provided a means of convergence, and also suffer from information overload that creates habitual practices that are not in agreement with the co-constructive practices. Some tweaks to threaded discussions, such as flattening the discussions (replies are only posted on the main topic) could help improve their ability to support co-constructive learning. However, knowledge building forums and anchored discussions show more promise (23).

One criticism of most studies involving discussion threads is that the participants are required to participate in the discussion threads, and this requirement could modify participant behavior. When participating in a threaded discussion is voluntary, some participants did decide to use threaded discussions (6). Participants decide to use threaded discussion because of past successes and because threaded discussions provide a dated archive of information. However, as noted in the previously stated studies, the content of the threaded discussions does not show co-constructive content, and participant surveys show that co-construction occurs in face-to-face meetings or through the use of other tools.

Discussion that are centered around an artifact (anchored discussions) show the potential to guide participants in co-constructive meaning-making (7). Because discussions can be placed within artifacts, participants are given a view of the discussion that illustrates the current state of the artifact and where new messages are more helpful than threaded discussions alone. Anchored discussion also provide mechanisms of convergence needed for co-construction.

4.2 Wikipages

Wikipages are a hyperlinked group of pages that are editable by participants. They often include threaded discussions where multiple participants can negotiate the content of the document. Like threaded discussions, wikipages are a popular form of online collaboration, and are the basic technology used to create an online encyclopedia with contributions from authors around the world (Wikipedia).

Wikipages can have an advantage in online collaboration because there are not many requirements that restrict the format of the document. Also, there are usually no assigned roles and participants can converge several ideas together in a single document. However, contributions can be both independent in nature and collaborative (28). Some contributions to a wikipage are independent thoughts that do not mix well with the other contributions, and other contributions build off of previous contributions. When analyzing contributions, it is important to differentiate between the two contributions (28).

4.3 Anchored Discussions

In the previous two sections we discussed the advantages and disadvantages of discussion threads and wikipages. We also discussed some solutions, one of which is anchored discussions. In this work, we use the term anchored discussions as a way to anchor a conversion or discussion in another artifact or notation. It has been shown that anchoring a chat to an artifact, or allowing participants to explicitly reference an artifact can improve learning scores (37). In this section, we will discuss various innovations to embed discussions within notations.

In an early study of the ecology of collaborations in an educational setting, it was shown that anchoring a discussion to an artifact of interest may increase the length of the discussion (17). Also to overcome practices of only reading recent contributions, mechanisms to highlight useful contribution may encourage participants to explore more of the contributions. Increasing the length (and hopefully the quality) of discussions and the ability to find the most useful contributions to discuss can provide a better co-constructive learning environment. Because of its co-constructive properties, many researchers has studied artifact centered discourse.

Suthers mentions three types of artifact centered discourse (56):

- parallel discourse where the artifact and the discussion are displayed on separate screens.

- embedded discourse where the discussion is embedded in the document.
- linked discourse where the discussion and artifacts contain links to each other.

Embedding and/or linking discussions to artifacts provides a mechanism for convergence, something threaded discussion lack.

Distributed textual discourse (DTD) allows participants to discuss and comment on textual documents through the use of hyperlinked comments that appear as footnotes in a document (36). Participants can link their comments to the text of an online document. Others can then comment on their comments to create a tree-like branching effect. (It is distributed because the content can be stored on different servers.) Another study shows that using a similar tool to discuss academic texts is less debate-like and more to the point than threaded discussion (67). These studies show anchored discussion improve co-construction, but it still does not provide a method of convergence, or a way for participants to link several posts together.

In order to encourage co-constructive knowledge building, a learning management system was developed so that students can turn in and share their work with other participants (34). After a student submits their assignment they can view other student's work and comment on that work through a threaded discussion below the submission. The discussion also appears on the assignment description page so that students can easily navigate to all the discussions. This system was used in a graduate-level design course, and showed that the discussion centered on students' design projects, and improved the quality of the discussion. However, all measurements are subjective. However, the mechanism of discussion, threaded discussions, does not provide a method of convergence, which could help improve co-constructive meaning-making.

Pink is a web based system that supports artifact centered discourse (65). Pink was created to discuss programming source code and security documents and focuses on embedded and linked discourse. Pink centers the discussion around the artifact and is designed to "summarize and share as a new artifact the created knowledge that becomes clear to participants in a discussion." Pink shows promise to support collaborative knowledge building, but it was only designed for source code and there is not any data gathered or evidence that it does indeed support co-constructive knowledge building.

Using the three types of artifact centered discourse mentioned above, another study simulates an asynchronous learning environment where dyads worked together to form hypothesis in a scientific study (58). In this study, participants using embedded discourse with a knowledge map created more hypotheses, discussed the hypotheses more, and scored higher on post-tests. This suggests that there was greater collaboration by using knowledge maps with embedded discourse. This experiment was done using downloadable software instead of a Web based solution.

Study	Summary	Results	Web based	Graphical
(17)	Anchored in articles	Increases length of discussions	Yes	No
(36)	Anchored comments in articles	No Data Collected	Yes	No
(67)	Anchored comments in articles	Supports Co-Construction	Yes	No
(34)	Discussions on student work	Suggests support for Co-construction	Yes	No
(65)	Anchored discussions on source code	No Data Collected	Yes	No
(58)	Anchored discussions with a knowledge map	Supports Co-Construction	No	Yes

Table 1: Summary of studies involving anchored discussions.

Table 1 contains a summary of the studies mentioned in this section. All of the studies that collect data show that anchored discussion support co-constructive meaning-making. Anchored discussion show a capacity to increase co-constructive learning, but only textual notations have been supported in a Web based learning environment. Creating graphical notations in a web based environment is more difficult. This is an area that can be explored further.

4.4 Concept Maps

A concept map is a graph with nodes and edges, with textual labels on both the node and edges (39). They have been used a long history (4), and they are useful in many topics including science education (40; 38). Concept maps are a generalized version of the knowledge maps that included anchored discussion (58), previously discussed in the “anchored discussion” section.

In another study (59), it was shown that “collaborative knowledge construction is more effectively supported by environments that make conceptual objects and relations explicit.” By using a threaded discussion as a control group and a graph representation (knowledge map) similar to context map, researchers were able to show that students elaborate more on contributions using a graph representation than a threaded discussion representation, and the data suggests that knowledge construction is more effectively supported by the graphic representation.

Concept maps have been shown to effectively create conditions in which collaborative learning is an effective means of knowledge construction (66). Concept maps make salient concepts and their relationships which means that participants easily see and manipulate important concepts and their relationship to other concepts. In another study, researchers have shown that concept maps (or knowledge maps) were more effective as a resource than text based material (44).

As discussed in the "Technological Support for Graphical Notations" section below, concept maps are difficult to create in an online learning environment. In (66)'s study, participants collaborated face-to-face using concept maps, and in (58) an independent software application was used to implement concept maps. In order to fully study the advantages of concepts maps, having an implementation that is connected with an online learning management system is needed to understand how instructors and students can unitize the system throughout a course.

4.5 Knowledge Building Environments

Knowledge building environments (KBEs) are are group of software tools created to allow the natural inventiveness of humans to be able to express themselves. The definition of knowledge building is the "creation and improvement of ideas that have a life out in the world, where they are subject to social processes of evaluation, revision, and application". The ideas apply in both educational and workplace environments. KBEs is "any environment (virtual or otherwise) that enhances collaborative efforts to create and continually improve ideas". KBEs distinguish themselves from CSCL tools by being capable to represent high-order organizations of ideas, spanning multiple disciplines, opportunistic linking of persons and groups, provide feedback to tap idea potential, and other elements (49).

CSILE and later Knowledge Forum were developed as a KBE that includes many of the features that support knowledge building. They are not a collection of notations or tools, but an environment where participants communicate and collaborate with models, media, and textual elements. A given contribution can appear in several different views, and participants can create graphical views that constitute a higher-level of organization. These tools are used in education (both K-12 and higher education), and the workplace including health care and business contexts. CSILE was built before the Web, and only includes local networking options. Knowledge Forum is online, but it is built as a web enabled java application that requires a download to run (46).

Although KBE distinguish themselves from CSCL, there are many graphical notations within a KBE. These graphical notations can be utilized to support co-constructive meaning-making. However, creating the graphical elements is difficult in an online environment (49), but new advances in web technologies, including HTML5, SVG, and AJAX could facilitate the development of these graphical tools in an online learning management system.

5 Technological Support

5.1 Graphical Notations

In order for learners to gain the most from collaborative learning, they need to merge their contributions together to build new knowledge (10; 49; 50). Interactive graphical notations (IGN) may provide better affordances for students to do so than purely textual notations. The notational systems used in IGN prompt relevant contributions and support integration by making both the organization of expressed information and what is structurally missing more salient (64; 63; 58). In contrast, the textual notation's viscosity and low visibility of structure and dependencies make it more difficult to modify (2).

Other work has also shown that graphical tools help increase co-construction. In a study involving a science challenge, graphical mapping tools appear to be more effective in supporting cooperative learning than textual representations (64). Knowledge maps with embedded notes have also been shown to more effectively support collaborative knowledge building (58). By using a content-specific visualization tool called CoStructure-Tool, dyads were more effective in integrating prior knowledge than dyads that used a general whiteboard (13). These studies all suggest that IGN help improve collaborative learning.

5.2 Technological Support for Graphical Notations

As discussed above, IGN have the potential to naturally support co-construction. However, creating IGN does require more effort from a technological standpoint, especially in Web based learning systems.

The most common way of creating IGN in an online environment is with a browser plugin (Adobe Flash) or a Java applet. These methods require two development efforts. One development effort is needed to create the web application, and another development effort is needed to create the IGN. Creating IGN this way requires developers to physically separate the IGN from the web site. These methods also require the users to install either the plugin or Java. Also, some mobile platforms, such as cell phones and touch tablets, do not support these technologies.

Using Java applets and other similar technologies several people have developed online concept maps, an IGN. The most comprehensive tools are the CmapTools (5). With CmapTools, users can create concept maps and post them online. All maps are viewable with a web browser, however to create or edit the concept maps, users need to download and install an application. Concept-Connector tools use an applet to implement concept maps in an

Notation	Co-construction Support	Web based	Graphical
Discussion threads	No convergence mechanism, less support	Easily Created	Textual
Wikipages	Changing text is less salient, less support	Easily Created	Textual
Concept Maps	Shows support	Not easy to build	Graphical
Anchored Discussions	Graphical types show support	Not easy to build	Graphical or Textual
KBEs	Highly Supportive	Not easy to build	Graphical (some textual)

Table 2: Summary of Notations.

online environment (35). Commercial products that include concept maps have also been developed (24; 51). All of these technologies require a browser plugin or applet.

An alternative to browser plugins and java applets are using scalable vector graphics (SVG) with Asynchronous Javascript with XML (AJAX). SVG and AJAX have an advantage because they do not require any additional plug-ins or downloads. SVG is mostly used to create online maps such as Google Maps or to create dynamic, data driven graphs. GeoBoost (12) is a geo-data visualization tool that uses SVG and AJAX. It also includes annotation tools built with SVG and AJAX. iMapping Wikis (18) is a zoomable-interface wiki. It allows users to create small wiki-like contributions, and then drag-and-drop these contributions in the workspace. Users can also link contributions together. iMapping Wikis requires users to download and install it, but the authors suggest using SVG and AJAX as an alternative method of implementation.

5.3 Context-Aware and Event-Based Systems

A context-aware system is a system that can remember the user's context while browsing multiple Web sites. For example, if you are looking for a book on a bookstore site, the context-aware system would know your location and insert results from your local library as well. A context-aware system can be seen as a personal data store, where the user controls their data and how that data is used. The context-aware system can apply personal data and modify the browsing experience to lead the user to better results.

Context-aware systems can also be seen as an event-based system. Instead of the request/response paradigm that the web uses, web sites and services can broadcast events to the system. Then using the personal data store of a user, the context-aware (or event-based) system can respond to the events in a customized manner. For example, a user can schedule a conference or meeting that requires travel in a calendar service. The service will broadcast an event that will cause the event-based system to see that travel is required, and then search for airfare, hotel, and car rentals and put the result in the calendar system for the user to review. When the user selects the flights, hotels, and car, the system books them using several services and the user's credit card information, and schedules them in the calendar. Then, when the user goes to travel, the user's GPS enabled mobile device broadcasts an event when the user reaches the airport. The event-based system can notify an expense report system (like expensify, which tracks credit card purchases to automatically generate expense reports) to start a new expense report for the trip. Then when the user arrives at the destination airport, his mobile devise launches another event, that the event-based system can use to notify the car rental company to prepare his car. The event-based system can then download the itinerary into the rental car's navigation system, and then the navigation system can broadcast events that notify the hotel and people he is meeting that he has arrived so they can meet him at the door.

Event-based and context-aware systems allows services to be loosely coupled and work together according to the user's preferences. Loosely coupled services allow the calendar service and the car rental company to share data without the calendar service and the car rental company creating a link to share the data, or even know about each other.

A context-aware/event-based system can be used in an educational setting to guide students to better collaborative learning practices. Since the goal of both of these systems is to loosely couple services together, they can be used to connect learning tools together in ways that the tools were not designed to do. For example, the system can replace a Learning Management System's discussion threads with social media tools found on different sites. Event-based systems can also be used to facilitate ad-hoc face-to-face meetings with participants in a class.

6 Conclusion

In this chapter, we reviewed the definition of Computer Supported Collaborative learning, overviewed the fundamental research methodologies used in the field and the theories used. We also reviewed several different notations that can support co-constructive meaning making and discussed technological support for co-constructive meaning-making.

6.1 Areas of Future Work

Research has shown that graphical notations can be more suited to support co-constructive meaning-making than textual notations like discussion thread and wikipages, but graphical notations are hard to create in Web-based learning environments. Therefore, there is little work done in evaluating graphical based tools in asynchronous online learning environments. New tools such as scalable vector graphics and AJAX can make it possible to easily create graphical notations in online learning environments. By creating these tools in traditional online learning environments, we can study how new tools support co-constructive meaning-making in an asynchronous online environment.

By using new technologies, we can explore different notations, especially graphical notations, integrated into online learning environments, and test them as they would be used in online or hybrid classes. We can see how graphical elements support co-constructive meaning making, versus textual elements, and tweak textual elements to see the effects on co-constructive meaning making.

Also, replacing discussion threads in traditional LMS's with professional or community web sites designed to support networked learning (or support collaboration in a professional community) could have several potential benefits including the following:

- It introduces tools that participants can use post-graduation.
- The reputation system provides additional motivation to participate in co-constructive meaning making.
- It provides ways for participants to network within the professional community.
- The participants can improve their employment applications by using community tools.

Because motivational factors exist outside of the course, LMS's that can include professional community sites could increase the amount of co-constructive meaning-making that takes place in the course, and the learning can be based on artifacts created by the professional community instead of the professor or students.

Integrating LMS's and professional sites can be accomplished through a context-aware system that is able to mashup different sites. By installing a browser extension, participants can search for answers in community based help sites. The browser extension would know which course the participant is taking and the question the participant has. When the participant finds an answer, the browser extension can store the question and answer the participant found in a central repository. Then when participants visit the LMS they will be able to see the questions and answers found by all the participants in the course.

An event-based system can also help participants collaborate through other means. The event-based system can receive and respond to events. Thus, when one participant logs into a social media or chat site, the event-based system can notify other participants in the course so that a synchronous discussion can be formed. Event-based systems can also use GPS enabled mobile devices to help arrange face-to-face meetings when participants are working in close proximity. Event-based systems can help speed up asynchronous communication media by notifying participants of new questions and encouraging collaboration. Giving participants a way to form face-to-face meetings and synchronous chats can provide better environments where co-constructive meaning-making can occur.

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