Chapter 1
Computer Support in E-Collaborative Learning-By-Doing Environments

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ABSTRACT

With the recent widespread use of computer and web technologies, web-based tools have been developed to mediate collaboration and facilitate knowledge construction. However, how to effectively design these tools to stimulate and maintain productive knowledge construction remains a challenge. This chapter describes a virtual learning-by-doing environment where students take the role of consultants to investigate the cause of recurring pipe corrosion in a paper processing company. We illustrate how the learning environment is designed to provide both pedagogical and technological support to collaborative knowledge construction. Our goal is to provide an example and offer guidance to professionals and educators who are interested building such virtual environments.

INTRODUCTION

The social theories of learning have demonstrated the importance of situating learning in social interactions and collaborations (e.g., Lave & Wenger, 1991; Hicks, 1996). Learning is no longer considered as a cognitive process that happens in an individual's mind, but a social process that often occurs through conversations as well as the collaborative construction of conceptual artifacts (e.g., Collins, Brown, & Newman, 1989; Graesser, Person, & Magliano, 1995; Palincsar & Brown, 1984). Meanwhile, knowledge construction, the ability to actively understand existing knowledge and create new ideas has become increasingly emphasized in education (Scardamalia, 2003). Students are often engaged in collaborative tasks where they negotiate ideas and construct knowledge based on each other's understanding (Roschelle & Teasley, 1995). Their collaboration results in continuous meaning making and learning (Stahl, Koschmann, & Suthers, 2006).

To facilitate collaborative knowledge construction, e-communication tools such as chat rooms, discussion forums, and videoconferencing have

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been used to allow geographically dispersed group members to work together. Research has found that computer-mediated collaboration can reduce production blocking in face-to-face collaboration (e.g. Gallupe, Bastianutti, & Cooper, 1991; Valacich, Dennis, & Nunamaker, 1992). Production blocking occurs when only one person can speak at one time. It causes difficulty in simultaneous idea generation and often leads to the loss of productivity (Diehl & Stroebe, 1987). Computer-mediated communication allows group members to present ideas simultaneously without the interference from peers. Multiple ideas can be generated at the same time. Furthermore, computer-mediated collaboration often allows one to view the performance of other team members and therefore causes the effect of social comparison (Festingerís, 1954). This comparison motivates one to outperform others and can result in the improvement in task performance (Munkes & Diehl, 2003). In addition, artifacts created in e-communication tools can be easily changed through redo and undo. They can be quickly duplicated through copy-and-paste and moved around through drag-and-drop. This allows learners to easily refine, reorganize, and augment their discussion. These artifacts can also serve as a permanent record and be used as the basis for future reflection. They can be adapted to provide scaffolding and representational formats appropriate to the competence of individual learners and the performance of the whole group (Stahl, Koschmann, & Suthers, 2006).

While e-communication tools have many advantages, how to effectively use them to stimulate and maintain productive knowledge construction remains a challenge. For example, while discussion forums have been found to produce more conversations with deeper thinking than face-to-face dialogues (Hawkes & Romiszowski, 2001), their structure makes them difficult for users to keep track of ideas brought up during discussion. Users tend to pay more attention to recent ideas rather than the ones discussed earlier (Hewitt, 2003). In addition, it is difficult for users to reference materials or representations outside the discussion forum. Users have to repeatedly go back and forth between their communication medium and the object under discussion. In addition, most of the communication tools lack the flexibility of providing multiple ways of representing and integrating ideas. This inevitably hinders the reorganization and connection of ideas in knowledge construction.

One way to support collaborative knowledge construction is to embed tools into a learning environment where students need to negotiate and share meaning construction through group interaction and negotiation. In this chapter, we discuss how to support collaborative knowledge construction in a learning-by-doing environment for problem-based learning. Problem-based learning has been proven as an effective pedagogy for collaborative knowledge construction (Bereiter & Scardamalia, 2003). It situates learning in the process of solving complex and ill-structured realistic problems (Hmelo & Evensen, 2000). Students work in groups to tackle problems more complex than what individuals could do alone (Hmelo, Narayanan, Newstetter & Kolodner, 1995). They are engaged in collaborative exploration, reflection, and articulation. Their problem solution represents the product of their shared meaning-making and knowledge construction (Schon, 1987; Brown & Campione, 1990; Scardamalia & Berierter, 1994).

In the following, we first describe background research related to collaborative knowledge construction. Then, we describe Corrosion investigator, a learning-by-doing environment where students can run simulated experiments, analyze data, generate hypotheses, and construct arguments. We further illustrate computational support in Corrosion Investigator specially designed to promote collaboration and knowledge construction. Our goal is to provide an example of how to support collaborative knowledge construction in learning-by-doing environments, and offer guidance and suggestions to professionals who are interested building such virtual environments.

BACKGROUND

Learn-by-doing is a pedagogical strategy that can be traced back to Dewey's educational philosophy. Dewey (1916) advocates that students should learn by actively manipulating artifacts and testing their ideas rather than passively absorbing knowledge from teachers. This idea has been supported by the situated cognition theory which shows learning as a process involved in the practical doings of things and situated in the practice of communities (Bateson 1976; Lave & Wenger, 1991). Cognition is viewed to take place through the interaction between a person and the environment rather than purely in the mind (e.g., Dewey & Bentley, 1949; Bickhard, 1992; Brown, Collins, & Duguid, 1989; Erickson & Schultz, 1982; Lave, 1988; Lave & Wenger, 1991; Schon, 1983). Kolb (1984) identifies four stages in learning: concrete experience, observation and reflection, the formation of abstract concepts, and testing in new situations. Doing is considered as the key in the first stage to initiate the learning process.

Collaborative learning (Slavin, 1990) engages students in learning-by-doing in a group setting. It is different from competitive and individual learning situations where students work against each other in order to perform better. Competitive learning generates negative interdependence that makes students either work harder than others or give up because they think there is little chance to win. Students often focus on their self-interest and consider their learning unrelated to others (Johnson & Johnson, 1989). In contrast, collaborative learning requires a team of students working together to accomplish learning goals (Artz & Newman, 1990; Slavin, 1990, 1991). Students have to share information, create ideas, and make learning progress as a team. Research has found that compared to comparative and individualistic learning, collaborative learning promotes higher learning achievement, greater social competence, and more supportive relationship (Johnson & Johnson, 1989; Stevens & Slavin, 1995). However, simply putting students in a team does not necessarily make them collaborate. Johnson, Johnson, and Holubec (1993) identified five critical factors to ensure effective collaboration. First, team members need to work towards a common goal. Each member should have his or her unique role in achieving the learning goal and be considered as indispensable to the group success. This helps students develop positive interdependence and make them feel one cannot succeed without the others. Second, the learning task should require students to share resources, discuss ideas, and teach each other. These supportive interactions will help students develop interpersonal commitment. Furthermore, Webb (1985) found that students learn better when they teach others and receive help. Third, individual accountability should be implemented so that each group member is accountable and assessed for his or her performance. This will help groups members know who needs assistance and who deserves applauds. It will reduce the problem of only a few members complete all the tasks. Fourth, students need to learn social skills to manage teamwork issues such as leadership, decision-making, trust-building, and conflict resolution. As conflicts and cooperation often co-exist (Johnson & Johnson, 1995), social skills will help students maintain healthy and supportive group relationships. Fifth, students should continuously improve their collaboration. They need to analyze each member's work and the collaboration between them to decide how to maintain good practices and discontinue ineffective strategies. All the above five elements are key factors in establishing effective collaboration. They help to maximize group performance as well as individual achievement.

Recent research on socially shared cognition provides other insights on how people create, distribute, and use knowledge in group settings (e.g., Higgins, 1992; Hinsz, Tindale, & Vollrath, 1997; Levine, Resnick, & Higgins, 1993; Nye & Brower, 1996; Resnick, Levine, & Teasley, 1991; Thompson, 1998). Cannon-Bowers, Salas, and

Converse (1993) found that groups often share mental models to help them coordinate their tasks and improve team performance. Mental models are knowledge structures that enable people to understand the behaviors of objects or environments around them (Johnson-Laird, 1983; Wilson & Rutherford, 1989, Rouse & Morris, 1986). In team collaboration, members need to share multiple mental models to obtain common understanding of the task as well as how to work as a team. These models facilitate teams to handle difficulties in cooperation and adapt to changing conditions (Cannon-Bowers et al., 1993). They include technology models that help team members understand how to interact with the tools that they use, task models that help members understand how the task should be accomplished in terms of procedures and strategies, team interaction models that describe how members should communicate and how information should flow, and team member models that contain information about each member's knowledge, attitudes, strength, and weakness (Cannon-Bowers et al., 1993). The above models can further be categorized as task-related models (e.g., the technology models and task models) and team-related models (e.g., the team interaction model and team member models) (Mclntyre & Salas, 1995; Morgan, Glickman, Woodard, Blaiwes, & Salas, 1986). These models affect communication, strategy, and interpersonal relationships in the team and consequently impact team performance (Klimoski & Mohammed, 1994; Mathieu, Goodwin, Heffner, Salas, & Cannon-Bowers, 2000). Team members develop better convergence in their mental models when they gain experience with their task and each other (Mathieu et al., 2000). When new comers enter a group, they have to learn the shared metal models in order to work effectively with the group (Moreland & Levine, 2008).

Besides shared mental models, research has been done to understand information sharing within a group. Larson (1997) found that shared information is discussed earlier than unshared information. Furthermore, shared information is discussed more often and thoroughly than unshared information (Larson & Harmon, 2007; Wittenbaum & Park, 2001). This is often caused by the person who leads the discussion of the group repeatedly directing the group's attention to previously discussed formation (Larson, Christensen, Franz, & Abbott, 1998). Research has also shown that when members have similar problem-solving styles, the group as a whole tends to perform better than its average members, but not necessarily better than its best members. However, when group members have very different problem-solving styles, the group as a whole performs better than its best members (Larson, 2007).

Social psychologists found social identities as another factor that affects group performance. Research has shown that despite shared interests and cooperative interdependence, team members tend to categorize themselves into different social categories (Tajfel & Turner, 1986; Turner, Hogg, Oakes, Reicher, & Wetherell, 1987). This causes positive affect such as trust and liking among members within the same category but also negative intergroup attitudes and discriminatory behaviors between members with different categorical identities (Brewer, 1979; Mullen, Brown, & Smith, 1992; Schopler & Insko, 1992). To solve this problem, several models have been developed to reduce intergroup conflict and prejudice. The personalization model (Brewer & Miller, 1984) proposes to have group members focus on each other's personal characteristics during interaction. It aims to replace categorical identity with personal identity. The common ingroup identity model (Gaertner, Mann, Murrell, & Dovidio, 1989; Gaertner, Mann, Dovidio, Murrell & Pomare, 1990; Gaertner, Dovidio, Anastasio, Bachman, & Rust, 1993) proposes to create new inclusive categories that include both the ingroup members and outgroup members. It aims to have team members think themselves as in one superordinate category rather than different subcategories. The above decategorization and recategorization models have been tested in experimental settings and proved to be effective in improving intergroup relations and producing more positive intergroup attitudes (Miller, Brewer, & Edwards, 1985; Bettencourt, Brewer, Croak, & Miller, 1992).

In the education domain, four learning-by-doing pedagogies have been identified as effective strategies that promote collaborative knowledge construction (Bereiter & Scardamalia, 2003). They include learning-by-design, project-based science, problem-based learning, and knowledge building. Learning-by-design engages students in the design of an artifact where students need to create their prototypes, collect performance data, and refine their designs (Holbrook & Kolodner, 2000). Project-based science situates learning in scientific inquiries where students need to answer challenging questions through the creation of authentic artifacts (Marx, Blumenfeld, Krajcik, & Soloway, 1997). Problem-based learning challenges students with complex and ill-structured problems to help them learn critical thinking and reasoning skills (Hmelo & Evensen, 2000). Knowledge building emphasizes the process of discovering new problems based on existing knowledge and develop new knowledge through solving the problem (Bereiter & Scardamalia, 2003). The above four pedagogies engage students in different learning activities, they all situate learning in a process where students need to collaboratively create an artifact, either in the form of a model, a product, or a report, and extend their knowledge by continuously elaborating on their ideas, making connections between existing knowledge, and finding opportunities for improvement and integration.

To facilitate collaborative knowledge construction, a number of software tools have been developed. For example, CoVIS (Edelson, Pea, & Gomez, 1995) and CSILE (Scardamalia & Bereiter, 1991) let students post data such as images and documents in common electronic workspaces to refute or support claims. They encourage students to bring information from various sources to generate different perspectives. Knowledge Forum (Bereiter & Scardamalia, 2003) allows students to construct notes and link them together to form concept maps. Students are encouraged to connect their own ideas with the work of their peers to present arguments and develop theories. Knowledge Forum further uses a series of prompts to encourage students to contribute ideas, organize information, and develop new understanding. It has been used by more than 250 schools, ranging from K-12 to graduate education, in a wide range of domains including biology, chemistry, philosophy, English, mathematics, and education. Studies have shown that the use of the Knowledge Forum improves students' collaborative skills and the quality of their collaborative inquiry (e.g., Bereiter, et al., 1997; Hewitt,2002; Oshima, 1977; Scardamalia, 2002; Scardamalia, Bereiter, & Lamon, 1994).

While the overall design of the learning environment determines the learning activities, the representational tools that students use impact the focus of their collaborative discourse (Suthers, Vatrapu, Medina, Joseph, & Dwyer, 2007). For example, graphical representations such as concept maps make students pay more attention to the relationships between their ideas. Students have been found to raise more hypotheses and discuss them more often when using concept maps than text-based discussion (Suthers & Hundhausen, 2003). The constraints and salience of different visual representations direct the focus of collaborative discourse to different aspects of the representations (Suthers, Vatrapu, Medina, Joseph, & Dwyer, 2008). It is important to choose the appropriate representational tools to mediate different learning tasks.

Artificial intelligence technology has recently been employed to facilitate collaborative knowledge construction. Back in the 1970s, artificial intelligence was mainly used to support individual learning by providing corrective feedback through the use of detailed cognitive modeling (Wenger, 1987). Starting in the mid 90s, artificial intelligence has been used to guide the process of discourse in collaborative learning. It identifies problems in the discussion based on dialogical theories (Hicks, 1996) and prompts students for further elaboration. For example, Belvedere is an e-learning environment where students construct evidence maps made up of nodes that are either hypotheses or evidence points in their scientific inquiry (Suthers, Connelly, Lesgold, Paolucci, Toth, & Weiner, 2001). Belvedere analyzes the augmentation structure of the evidence map by comparing it with the one generated by subject matter experts and provides coaching on how to improve the consistency and completeness of the argument. While empirical results have shown that Belvedere can effectively assist collaborative argument construction (Suthers, Connelly, Lesgold, Paolucci, Toth, Toth, & Weiner, 2001), its technology is based on the analysis of the structure of the argument rather than its meaning. Providing accurate feedback based on true understanding of the argument still remains a challenge.

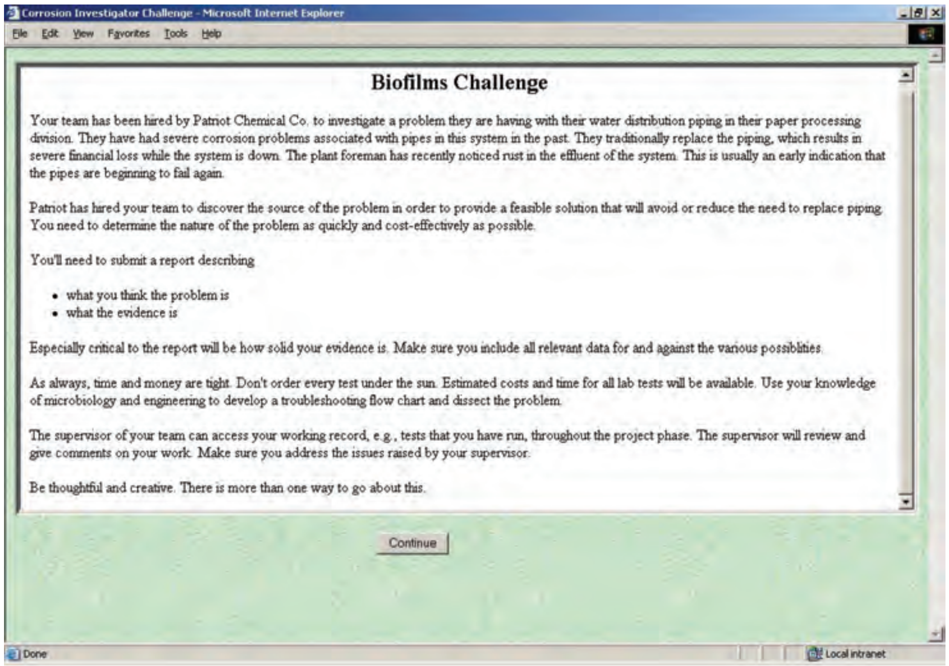
The e-learning environment, Corrosion Investigator, described in this chapter is based on goal-based scenario (GBS) (Schank, Fano, Bell, & Jona, 1993; Schank & Neaman, 2001), a framework for constructing interactive learn-by-doing environments. GBS focuses on creating realistic settings where students play real-life roles to solve challenging problems. For example, Sickle Cell Counselor (Bell, Bareiss, & Beckwith, 1994) is a GBS environment where students work as reproductive counselors advising newly married couples on their children's risk of having sickle cell disease. Volcano Investigator is a GBS environment where students play the role of geologists to investigate the likelihood of volcano eruption in a small town (Dobson, 1998). These learning environments use fictional scenarios with videos and simulations to create engaging settings, and provide video clips of expert advice and automatic critiquing to guide student learning. While GBS environments have been used to teach students problem-solving and provide on-the-job training for professionals, previous GBS environments are only for individual learners. Corrosion Investigator extends the GBS framework by providing collaboration support such as data sharing and argument construction in the learning environment. It is designed to facilitate a group of students to share and interpret the data that they collected and argue about the conclusions that they can draw from the data. In the following, we briefly introduce Corrosion Investigator and then discuss its design for collaborative knowledge construction.

SOFTWARE INTERFACE

Corrosion Investigator is a learning-by-doing environment designed for collaboratively problem-solving. Its focus is to provide a structured environment with authentic simulated data and a set of tools to direct and facilitate collaboration. It is not intended to be used as the only medium through which students collaborate. Students can use it either during classroom hours or outside of the class. They can communicate face-to-face or through existing tools such as instant messengers to discuss their problem-solving strategies and coordinate their collaboration. Corrosion Investigator is aimed to be used as a focal point for students to share data, propose and defend ideas, and receive coaching.

When students first enter Corrosion Investigator, a *challenge* screen (see Figure 1) tells them that they need to work as engineering consultants to diagnose the cause of two corrosion problems in a paper processing company. After reading the challenge, students can go to the *reference* screen. This screen contains background information about the company, including the location and condition of the corrosion and four characters that students can contact for more information: the plant foreman, the plant manager, the scientific consultant and the supervisor. Questions directed to these characters will be forwarded to the instructor and the instructor will provide answers to students' questions.

Figure 1. The challenge screen in corrosion investigator



To diagnose the corrosion problem, students go to the *experiment* screen to run experiments (see Figure 2). The left-hand side of the screen has a *notebook*. It collects all the experiment results that students receive from the system and splits them into single items with labels indicating their experiment names and conditions. Items in the notebook are clickable. Students can select them to use as evidence in their report. The right-hand side of the *experiment* screen allows students to look for experiments by entering experiment names into a textbox. Experiments matching the name will be shown.

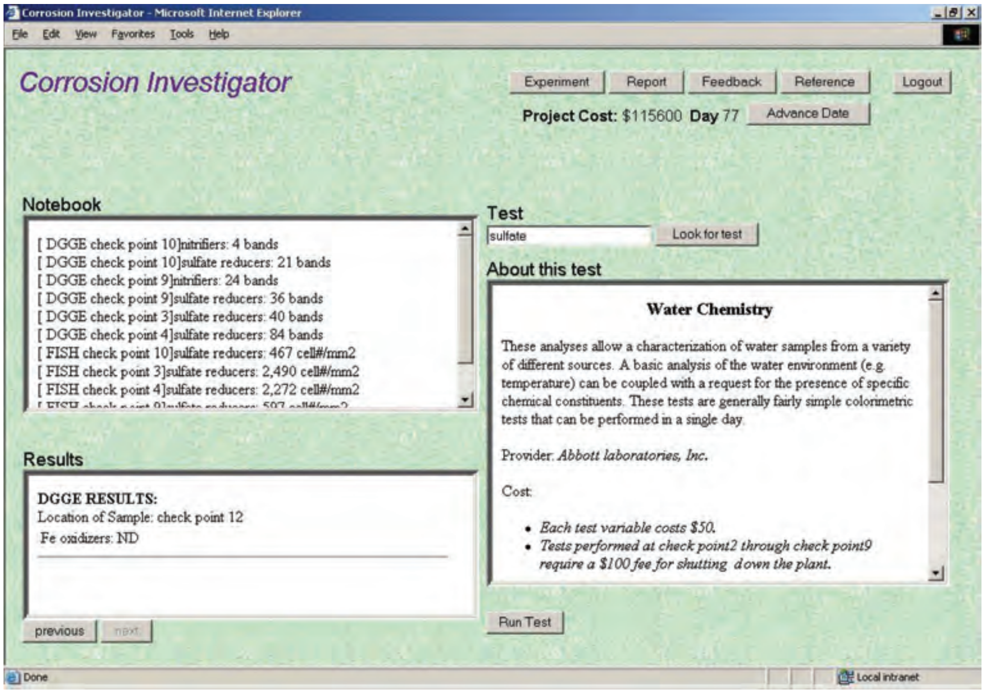
When students decide to run an experiment, they can specify the parameters for the experiment on a separate screen (see Figure 3). Experiments in Corrosion Investigator often have complex options so that students have to think hard about which experiments to run. The *cost* and *delay* field displays the simulated amount of money and the days that the experiment takes. These values are dynamically calculated and displayed based on the parameter selection. They will be added to the value of the *project cost* and *day* field on the top of the screen, if students choose to run the experiment. These fields remind students to solve the challenge using minimum time and money. Before running an experiment, students need to enter reasons for ordering the experiment.

To receive experiment results, students need to press the *advance date* button at the top of the screen to advance the simulated project date to the time when the most recent experiment results are available. New experiment results automatically appear in the *notebook* and *result* area on the *experiment* screen.

The *report* screen allows students to construct their report using experiment results as evidence (see Figure 4). Students can select a result in the *notebook* and enter the reason for using the result. When students complete their report, they can submit it for evaluation.

While students are working in the system, their work is recorded and organized as a report for their instructor to review. The instructor can add comments to the students' work. Students can

Figure 2. The experiment screen in corrosion unvestigator



review these comments on the *feedback* screen, and provide responses (see Figure 5).

DESIGN FOR COLLABORATIVE KNOWLEDGE COSTRUCTION

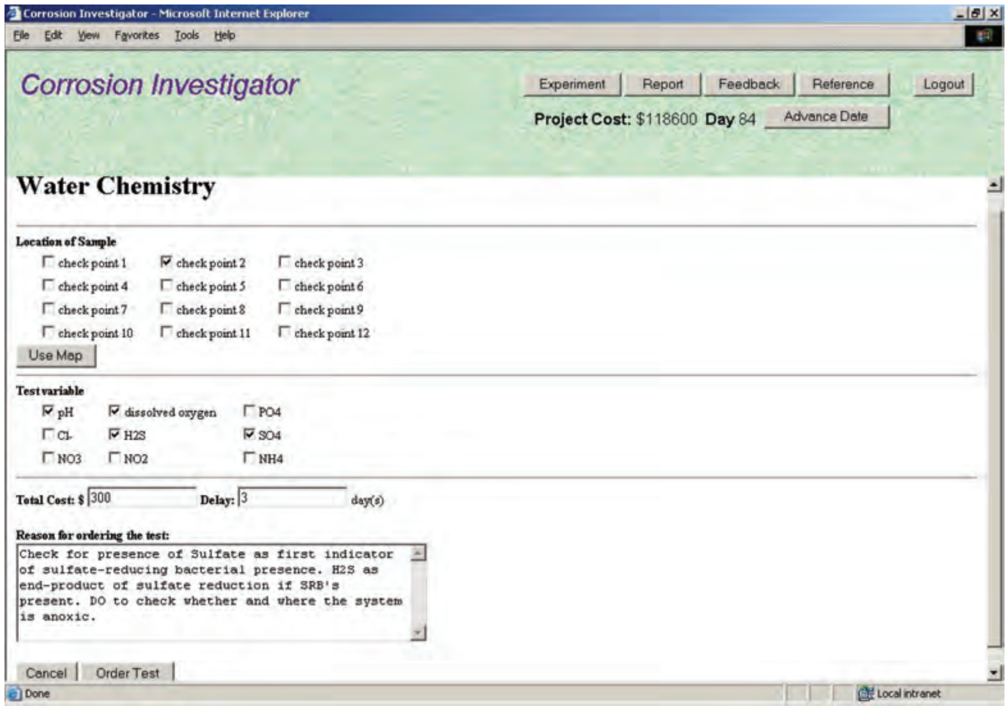
In the following, we discuss computational supports in Corrosion Investigator designed for collaborative knowledge construction. These supports allow students to actively participate in collaborative problem-solving and develop artifacts that represent the product of their knowledge construction.

Shared Problem-Solving Task to Foster Collaboration

Collaborative knowledge construction requires each group member to make sense of others' understanding and advance the knowledge of the whole group through negotiation and elaboration. It is critical to maintain a shared understanding of the problem at hand so that new ideas can be developed based on this common ground (Cannon-Bowers et al., 1993). In Corrosion Investigator, the notebook provides a common knowledge repository for students to share their findings. It automatically collects all the experiment data generated by students so that students do not need to combine their findings together. It ensures that all members in the collaboration have access to the same knowledge base.

For collaborative learning to be effective, team members need to have a common group goal (Slavin, 1996; Johnson & Johnson, 1989, 1990). In Corrosion Investigator, we develop a task setting where group members share the cost and result of each other's action. Each experiment has a time delay and cost. Whenever a student runs an experiment, the time and cost of the experiment will be automatically added to the total time and cost spent by the whole group. Different from environments where individuals bear the cost of their

Figure 3. The parameter value selection screen in corrosion investigator



own actions, Corrosion Investigator automatically accumulates the cost of each individual's action on a group level. This makes the action of every student directly impact the performance of the whole group. Students have to coordinate their actions and formulate team strategies to minimize the cost of their investigation. The individual accountability and shared responsibility make the problem-solving task a collaborative effort rather than an individual endeavor (Johnson, Johnson, & Holubec, 1993).

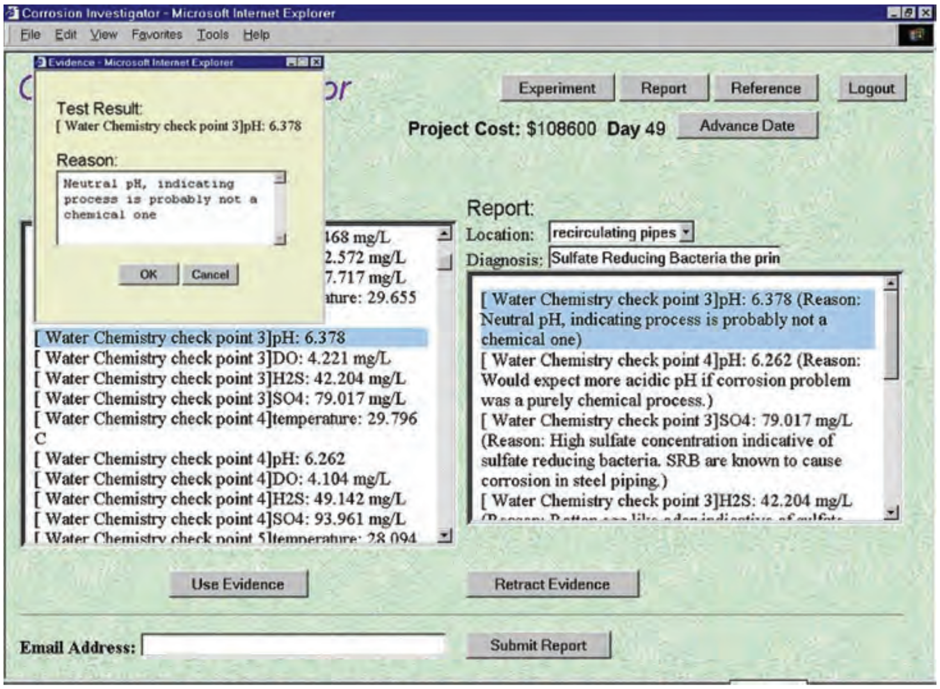
In virtual environments, participants often feel isolated due to the remote nature of the communication medium (Puntambekar, 1996). In Corrosion Investigator, we provide a progress report to help students obtain an overall picture of their group activities. The report combines all the actions that individual members have performed in chronicle order. It allows students to quickly review activities performed by other team members and understand the progress of the whole group. Every student receives the opportunity to develop a sense of being a member in a community and see how his/her activities fit into the team effort.

Structured Interface for Collaborative Argument Construction

In collaborative knowledge constructions, team members need to exchange and negotiate ideas to develop new knowledge. The argument construction tool in Corrosion Investigator allows students to argue about and reflect on each other's ideas. Students can collect evidence to support their hypotheses, or provide contradictory data to refute their hypotheses. Through this argumentation process, students will develop a better understanding of the corrosion problem, the underlying causes of the problem, and the relationship between the causes.

In addition, different user interfaces representations offer different affordances (Norman, 1999).

Figure 4. The report screen in corrosion investigator



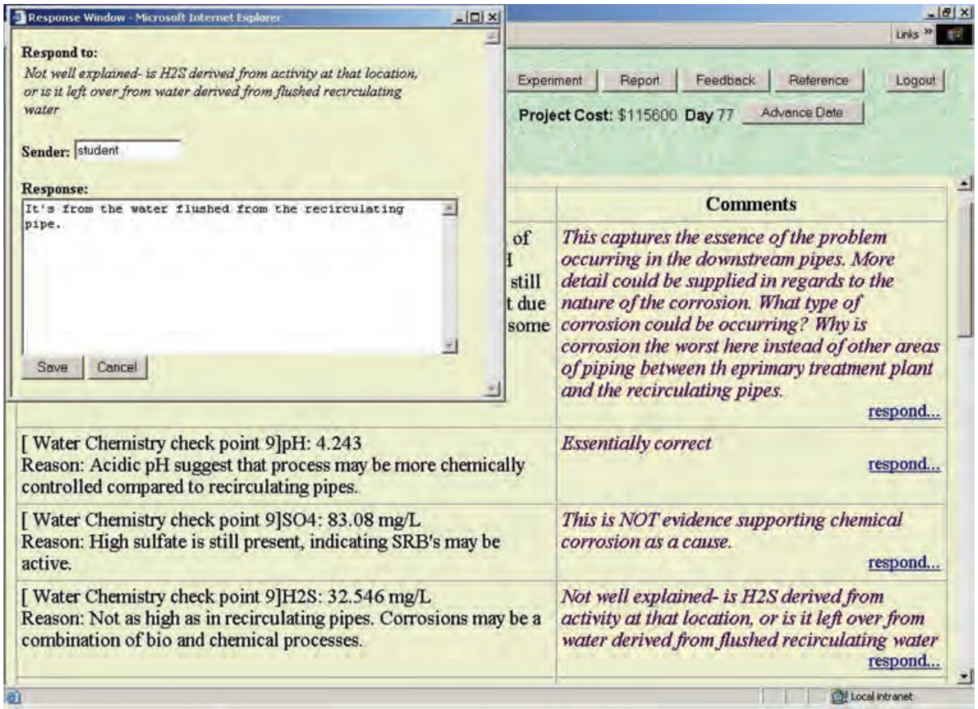
The design of user interfaces can direct students' focus to different aspects of their learning and lead them through different learning courses (e.g., Baker & Lund, 1996; Dillenbourg, 2005; Guzdial & Hmelo, 1997; Suthers & Hundhausen, 2003; Suthers et al., 2007). In Corrosion Investigator, we structure the argument construction interface to require students to always create a hypothesis first and then add evidence to argue about their hypothesis. This ensures students to follow the typical scientific inquiry process where hypotheses are generated first and then verified by experimental data. It also helps to center students' discussion around their hypotheses. The goal is to avoid the problem in standard discussion forums where participants often lose concentration and cannot generate a conclusion in the end (Hewitt, 2001).

The argument construction tool also requires students to provide experimental evidence for every argument point that they make. This ensures that students' arguments are always grounded on real data. To help students use experimental evidence in their arguments, the argument construction tool is closely integrated with the data collection notebook. Students can select an experiment result from the notebook, attach a note to explain why he or she wants to use the result, and insert it into the argument. While the requirement of using experimental data for every argument point may limit the flexibility of argument construction, preliminary results show that argument reports generated using the tool have the same quality as the ones generated in face-to-face collaboration (Qiu, 2005).

Coaching for Problem-Solving and Reflection

Problem-based learning encourages students to pursue free exploration and direct their own learning. While this strategy allows students to learn in a realistic setting, students often miss key learning resources or fail to think deeply. It is essential to have teachers provide just-in-time

Figure 5. The feedback screen in corrosion investigator



coaching to help students reach expected learning goals (Collins, Brown, & Newman, 1989).

In Corrosion Investigator, we provide an interactive report for teachers to review student activities in the learning environment. The report includes the time and money that students have spent, experiments that students have scheduled and run, reasons for running those experiments, and hypotheses and arguments that students have created. Teachers can click on items in the report and add critiques. The interactive report is automatically updated every time when students perform an action in the learning environment.

The interactive report allows teachers to work closely alongside with students to provide critiquing. Empirical results show that teacher's critiquing often provokes students to reflect on their own thinking (Qiu, 2005). We analyzed 32 critiques collected during two preliminary studies and found that these critiques can be categorized into three types. The first type confirms the correctness of the student's thinking. For example,

"That is correct- H2S a byproduct of SRB metabolism."

The second type points out that the student thinking is incorrect. For example,

"This is NOT evidence supporting chemical corrosion as a cause."

The third type asks for more explanation. For example,

"Why is corrosion the worst here instead of other areas of piping between the primary treatment plant and the recirculating pipes?"

"More detail could be supplied in regards to the nature of the corrosion."

"There are other possibilities for chemical corrosion at neutral pH's - should acknowledge this."

These critiques prompt students to correct their misunderstanding or help them develop further knowledge by confirming their reasoning. The inclusion of teachers in the learning environment facilitates students to develop knowledge that is valid and complete.

Technological Implementation for Collaborative Knowledge Construction

Online collaborative knowledge construction requires students to participate from different locations. It presents unique technical challenges for learning-by-doing environments. Up until the early 2000s, learning-by-doing environments are all built as monolithic systems. They use immersive multimedia to create engaging settings and scaffolding tools to support problem-solving. For example, Alien Rescue (Liu, Williams, & Pedersen, 2002) is a learning environment where students need to find a new home in the solar system for aliens to survive. BioWorld (Lajoie, Lavigne, Guerrera, & Munsie, 2001) is a learning environment for students to diagnose patients in a simulated hospital setting. These learning environments are installed on individual computers and cannot be accessed remotely from other machines. This makes them difficult to support collaboration. In the following, we describe the technological support in Corrosion Investigator for collaborative knowledge construction.

Accessibility

Web-based interfaces allow team members to collaborate through web browsers. There is a wide range of options to implement the web-based interface. Standard HTML pages are widely accessible from any web browser on any platform. They are, however, not very interactive. JavaScript webpages introduce more interactions, but they can only provide limited options such as textboxes and drop-down menus. Plug-in based tools such as Flash support integration of video, audio, and graphics for richer interactivity. However, they typically run on Windows, sometimes on Mac OS, but are not fully supported on other platforms such as Linux. To encourage participation, it is important to use the technology that is widely accessible from different platforms and maintain the capability to support interactive activities.

In Corrosion Investigator, student learning activities include choosing experiments, specifying parameters, receiving data, and constructing arguments. They do not require complex interactions such as drawing diagrams. Therefore, we use standard JavaScript for the user interface. The Javascript implementation allows the interface to be easily accessible from modern web-browsers such as Internet Explorer and Netscape without special software plug-ins. It provides wide deployability with the least commitment to third-party vendor support. This lowers the technical barrier for using the learning environment and allows students to participate with minimum technical requirement.

Data Consistency

Learning-by-doing environments need to make sure that information presented to every student is always consistent and up-to-date. In Corrosion Investigator, we save the learning content and student activities into a central server and loads data from the server whenever students interact with the learning environment. This ensures that every student has access to the most current experiment data generated by the team. The storage of learning content on the server also facilitates the authoring of the learning environment (Qiu & Riesbeck, 2008). With a web-based authoring tool, authors can modify the learning content anytime, anywhere through web browsers. When the learning content is modified, students can immediate see the change in their web browsers because the learning environment is constructed real-time from the server.

The storage of student activities on the server allows instructors to easily access them in a centralized location. Instructors no longer need to collect student records from individual machines. They can view these records through web-based interactive reports that we provide. The report is updated every time a student makes a move in the learning environment so that the instructor always sees the most recent student activity.

Interactivity

Learning-by-doing environments need to be highly interactive because students need to perform problem-solving activities such as exploring background information, running experiments, and comparing results. Speed is one of the key factors in determining interactivity. Users often accept delays of one to two seconds, but no more than ten to fifteen second (Olsen, 1998). Therefore, it is important to provide immediate feedback to keep the learning activity interactive and engaging.

In Corrosion Investigator, we run the program that generates complex experiment results on the server and run the program that handles user interactions in the web browser. For example, students' experiment requests are sent to the server for processing. These requests require complex algorithms and simulations with multi-parameter constraints. Running them on the server reduces the time needed and avoids the requirement to have powerful computational capability on students' machines. In contrast, the dynamic display of cost and time of an experiment is handled by JavaScript run in the web browser. Students can immediate see the change of the cost and time when they choose different parameter values. This allows students to easily explore different experiment options without long-time delay. Students can have fast interactivity even when their network bandwidth is low.

The above describes the pedagogical and technological support in Corrosion Investigator for collaborative knowledge construction. We have conducted preliminary evaluation studies and results have been promising (Qiu, 2005). More thorough evaluative research is underway.

FUTURE RESEARCH DIRECTIONS

In Corrosion Investigator, we introduced an instructor into the learning environment to critique student learning. We plan to use natural language processing techniques such as Latent Semantic Analysis (LSA) (Foltz, 1996; Landauer & Dumais, 1997; Landauer, Foltz, & Laham, 1998) to provide automatic feedback to students' arguments. LSA has been used successfully in AutoTutor (Graesser, Wiemer-Hastings, Wiemer-Hastings, Harter, Person, & the TRG, 2000) to compare student writings against stored examples and provide suggestive comments. In Corrosion Investigator, we plan to use LSA to compare students' reasons for running an experiment with stored examples of correct and wrong reasons, and return corresponding critiques. While the potential to provide automatic feedback remains promising, it is important to note that computers can easily lose credibility if users notice inappropriate feedback (Reeves & Nass, 1996). When users have low trust of computers, they pay little attention to the feedback even when it is correct. The need for extremely accurate feedback significantly increases the difficulty of building learning systems with automatic coaching capability. For example, intelligent tutoring systems that provide individualized feedback often require two hundred hours of development for one hour of instruction (Woolf & Cunningham, 1987). Future research is needed to develop effective and inexpensive methods for automatic feedback generation.

While collaborative learning-by-doing environments change the traditional learning practice into a collaborative effort, they also change the social relationships among their users (Levin & Kareev, 1980). Several studies have found that the use of computers in the classroom reduces teacher-centered activities and weakens teachers' authority role (e.g., Gearhart, Herman, Baker, Novak, & Whitteier, 1994). When students have access to individuals or information resources more knowledgeable than their teachers, they become less dependent on their teachers (Schofield, 1995). Student-student relations also become more cooperative as students work as collaborators rather than simply classmates (Hawkins, Sheingold, Gearhart, & Berger, 1982). These social impacts of learning software should be fully aware by technology adopters.

Educational games have recently received a lot of attention. Games such as Second Life provide immersive and animated environments for anyone in the world to access. Research has shown that students are fairly comfortable of using avatar to represent themselves in games and carry out collaborative learning activities (Virvou, Katsionis, & Konstantinos, 2005). Pedagogical agents in such games can stimulate student learning and maintain high level of engagement (Conati & Zhao, 2004). With these new technologies, students can interact with their team members (including computer agents) in 3D environments that are much more natural than chat rooms or discussion forums. They can construct virtual artifacts similar to the ones in real life. With these new developments, the study of knowledge construction in immersive environments becomes an emerging topic worth further investigation.

Besides learning, virtual environments have also been employed for studying social behaviors. Blascovich, Loomis, Beall, Swinth, Hoyt, and Bailenson (2002) found that virtual environments can reduce methodological issues in traditional experimental settings such as the lack of replication and unrepresentative sampling. Furthermore, when social behaviors happen in a virtual environment, researchers can perform "reverse engineering" by manipulating components in the virtual environment to understand the cause of particular behaviors and identify their components. This helps researchers perform more fine-grained examination of social behaviors and their elements.

CONCLUSION

In this chapter, we described Corrosion Investigator, a virtual learning-by-doing environment where students take the role of consultants to investigate the cause of recurring pipe corrosion in a paper processing company. We discussed how to provide support to e-collaborative knowledge construction by a) creating a shared task to engage students in collaboration, b) providing an argument construction tool to facilitate idea exchange and knowledge construction, c) providing instructor coaching to guide problem-solving, and d) using technological implementation to ensure data consistency, accessibility, and interactivity. The synergy of the above design provides multi-level support for collaborative knowledge construction. We believe it serves as an example of how to design learning-by-doing environments to effectively support collaborative knowledge construction.

REFERENCES

Artz, A. F., & Newman, C. M. (1990). Cooperative learning. *Mathematics Teacher*, *83*, 448–449.

Baker, M. J., & Lund, K. (1996). Flexibly Structuring the Interaction in a CSCL environment. In P. Brna, A. Paiva & J. Self (Eds.), *Proceedings of the EuroAIED Conference* (pp. 401-407). Lisbon, Portugal: Edições Colibri.

Barrows, H. S. (2000). *Problem-based learning applied to medical education*. Springfield, IL: Southern Illinois University Press.

Bateson, G. (1976). Some Components of Socialization for Trance. In Schwartz, T. (Ed.), *Socialization as Cultural Communication* (pp. 51–63). Berkeley, CA: University of California Press.

Bell, B. L., Bareiss, R., & Beckwith, R. (1994). Sickle cell counselor: a prototype goal-based scenario for instruction in a museum environment. *Journal of the Learning Sciences*, *3*, 347–386. doi:10.1207/s15327809jls0304_3

Bereiter, C., & Scardamalia, M. (2003). Learning to Work Creatively With Knowledge. In De Corte, E., Verschaffel, L., Entwistle, N., & Van Merriënboer, J. (Eds.), *Unravelling basic components and dimensions of powerful learning environments*. EARLI Advances in Learning and Instruction Series.

Bereiter, C., Scardamalia, M., Cassells, C., & Hewitt, J. (1997). Postmodernism, knowledge building, and elementary science. *The Elementary School Journal*, *97*, 329–340. doi:10.1086/461869

Bettencourt, B. A., Brewer, M. B., Croak, M. R., & Miller, N. (1992). Cooperation and reduction of intergroup bias: The role of reward structure and social orientation. *Journal of Experimental Social Psychology*, *28*, 301–319. doi:10.1016/0022-1031(92)90048-O

Bickhard, M. H. (1992). How Does the Environment Affect the Person? In Winegar, L. T., & Valsiner, J. (Eds.), *Children's Development in Social Context*. Hillsdale, NJ: Lawrence Erlbaum Assoc.

Blascovich, J., Loomis, J., Beall, A. C., Swinth, K. R., Hoyt, C. L., & Bailenson, J. N. (2002). Immersive virtual environment technology as a methodological tool for social psychology. *Psychological Inquiry*, *13*, 103–124. doi:10.1207/S15327965PLI1302_01

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (1999). *How people learn: Brain, Mind, Experience, and School*. Washington, DC: National Academy Press.

Brewer, M. B. (1979). In-group bias in the minimal intergroup situation: A cognitive-motivational analysis. *Psychological Bulletin*, *86*, 307–324. doi:10.1037/0033-2909.86.2.307

Brewer, M. B., & Miller, N. (1984). Beyond the contact hypothesis: Theoretical perspectives on desegregation. In Miller, N., & Brewer, M. (Eds.), *Groups in contact: The psychology of desegregation* (pp. 281–302). New York: Academic Press.

Brown, A. L., & Campione, J. C. (1990). Communities of learning and thinking, or a context by any other name. In D. Kuhn (Ed.), Contributions to Human Development, 21, 108-125.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32–42.

Cannon-Bowers, J. A., Salas, E., & Converse, S. A. (1993). Shared mental models in expert team decision making. In Castellan, N. J. Jr., (Ed.), *Current issues in individual and group decision making* (pp. 221–246). Hillsdale, NJ: Erlbaum.

Chicago: Open Court.

cognitive theory and classroom practice (pp. 201-228). Cambridge, MA: MIT Press.

Collins, A., & Brown, J. (1988). The computer as a tool for learning through reflection. In Mandl, H., & Lesgold, A. (Eds.), *Learning issues for intelligent tutoring systems*. New York: Springer Verlag.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive Apprenticeship: Teaching the crafts of reading, writing and mathematics. In Resnick, L. (Ed.), *Knowing, Learning and Instruction*. Hillsdale, NJ: Erlbaum.

Collins, E., & Green, J. L. (1992). Learning in classroom settings: making or breaking a culture. In Marshall, H. H. (Ed.), *Redefining student learning: roots of educational change*. Norwood, NJ: Ablex.

Conati, C., & Zhao, X. (2004). Building and Evaluating an Intelligent Pedagogical Agent to Improve the Effectiveness of an Educational Game. In *Proceedings of International Conference on Intelligent User Interfaces 2004*.

Derry, S. J., Hmelo-Silver, C. E., Nagarajan, A., Chernobilsky, E., & Beitzel, B. (2006). Cognitive transfer revisited: Can we exploit new media to solve old problems on a large scale? *Journal of Educational Computing Research*, *35*, 145–162. doi:10.2190/0576-R724-T149-5432

Dewey, J. (1916). *Democracy and Education*. New York: MacMillan.

Dewey, J., & Bentley, A. (1949). *Knowing and the Known*. Boston, MA: Beacon Press.

Diehl, M., & Stroebe, W. (1987). Productivity loss in brainstorming groups: Toward the solution of a riddle. *Journal of Personality and Social Psychology*, *53*, 497–509. doi:10.1037/0022-3514.53.3.497

Dillenbourg, P. (2005). Designing biases that augment socio-cognitive interactions. In Bromme, R., Hesse, F. W., & Spada, H. (Eds.), *Barriers and Biases in Computer-Mediated Knowledge Communication-and How They May Be Overcome*. Dordrecht, The Netherlands: Kluwer. doi:10.1007/0-387-24319-4_11

Dobson, W. D. (1998). *Authoring tools for investigate and decide learning environments*. Unpublished doctoral dissertation, Northwestern University, Evanston.

Dochy, F., Segers, M., Van den Bossche, P., & Gijbels, D. (2003). Effects of problem-based learning: A meta-analysis. *Learning and Instruction*, *13*, 533–568. doi:10.1016/S0959-4752(02)00025-7

Edelson, D. C., Pea, R. D., & Gomez, L. (1995). Constructivism in the collaboratory. In Wilson, B. G. (Ed.), *Constructivist learning environments: Case studies in instructional design* (pp. 151–164). Englewood Cliffs, NJ: Educational Technology Publications.

Erickson, F., & Schultz, J. (1982). *The Counselor as Gatekeeper: Social Interaction in Interviews*. New York: Academic Press.

Festinger, L. (1954). A theory of social comparison processes. *Human Relations*, *7*, 117–140. doi:10.1177/001872675400700202

Foltz, P. W. (1996). Latent semantic analysis for text-based research. *Behavior Research Methods, Instruments, & Computers*, *28*(2), 197–202.

Gaertner, S. L., Dovidio, J. F., Anastasio, P., Bachman, B. A., & Rust, M. (1993). The Common Ingroup Identity Model: Recategorization and the reduction of intergroup bias. In Stroebe, W., & Hewstone, M. (Eds.), *European review of social psychology* (*Vol. 4*, p. l-26). Chichester, UK: Wiley.

Gaertner, S. L., Mann, J., Dovidio, J. F., Murrel, A., & Pomare, M. (1990). How does cooperation reduce intergroup bias? *Journal of Personality and Social Psychology*, *59*, 692–704. doi:10.1037/0022-3514.59.4.692

Gaertner, S. L., Mann, J., Murrel, A., & Dovidio, J. F. (1989). Reducing intergroup bias: The benefits of recategorization. *Journal of Personality and Social Psychology*, *57*, 239–249. doi:10.1037/0022-3514.57.2.239

Gallupe, R. B., Bastianutti, L. M., & Cooper, W. H. (1991). Unblocking brainstorms. *The Journal of Applied Psychology*, *76*(1), 137–142. doi:10.1037/0021-9010.76.1.137

Graesser, A. C., Person, N. K., & Magliano, J. P. (1995). Collaborative dialogue patterns in naturalistic one-on-one tutoring. *Applied Cognitive Psychology*, *9*, 495–522. doi:10.1002/acp.2350090604

Graesser, A. C., Wiemer-Hastings, P., Wiemer-Hastings, K., Harter, D., & Person, N.TRG. (2000). Using Latent Semantic Analysis to Evaluate the Contributions of Students in AutoTutor. *Interactive Learning Environments*, *8*, 128–148. doi:10.1076/1049-4820(200008)8:2;1-B;FT129

Guzdial, M., & Hmelo, C. (1997). Integrating and guiding collaboration: Lessons learned in computer-supported collaborative learning research at Georgia Tech. In Proceedings of Computer Supported Collaborative Learning '97, Toronto, Ontario (pp. 91-100).

Hawkes, M., & Romiszowski, A. (2001). Examining the reflective outcomes of asynchronous computer-mediated communication on in service teacher development. *Journal of Technology and Teacher Education*, *9*(2), 285–308.

Hawkins, J., Sheingold, K., Gearhart, M., & Berger, C. (1982). Microcomputers in schools: Impact on the social life of elementary classrooms. *Journal of Applied Developmental Psychology*, *3*, 361–373. doi:10.1016/0193-3973(82)90008-9

Hewitt, J. (2001). Beyond Threaded Discourse. *International Journal of Educational Telecommunications*, *7*(3), 207–221.

Hewitt, J. (2002). From a focus on tasks to a focus on understanding: The cultural transformation of a Toronto classroom. In T. Koschmann, R. Hall, & N. Miyake (Eds.) Computer Supported Cooperative Learning Volume 2: Carrying forward the conversation, (pp. 11-41). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Hewitt, J. (2003). How habitual online practices affect the development of asynchronous discussion threads. *Journal of Educational Computing Research*, *28*(1), 31–45. doi:10.2190/PMG8-A05J-CUH1-DK14

Hicks, D. (1996). Contextual inquiries: A discourse-oriented study of classroom learning. In Hicks, D. (Ed.), *Discourse, learning and schooling* (pp. 104–141). New York: Cambridge University Press.

Higgins, E. T. (1992). Achieving "shared reality" in the communication game: A social action that creates meaning. *Journal of Language and Social Psychology*, *11*, 107–131. doi:10.1177/0261927X92113001

Hinsz, V. B., Tindale, R. S., & Vollrath, D. A. (1997). The emerging conceptualization of groups as information processors. *Psychological Bulletin*, *121*, 43–64. doi:10.1037/0033-2909.121.1.43

Hmelo, C., Narayanan, N. H., Newstetter, W. C., & Kolodner, J. L. (1995). *A multiple-case-based approach to generative environments for learning.* Paper presented at the Second Annual Symposium on Cognition and Education.

Hmelo, C. E., & Evensen, D. H. (2000). Introduction. In Evensen, D. H., & Hmelo, C. E. (Eds.), *Problem-Based Learning, A Research Perspective on Learning Interactions* (pp. 185–195). Mahwah, NJ: Lawrence Erlbaum Associates.

Hmelo-Silver, C. E., & Barrows, H. S. (2006). Goals and strategies of a problem-based learning facilitator. *Interdisciplinary Journal of Problem-based Learning*, *1*, 21–39.

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist*, *42*, 99–107.

Holbrook, J., & Kolodner, J. L. (2000). Scaffolding the development of an inquiry-based (science) classroom. In B. Fishman & S. O'Connor-Divelbiss (Eds.), *Fourth International Conference of the Learning Sciences* (pp. 221-227). Mahwah, NJ: Lawrence Erlbaum Associates.

Johnson, D. W., & Johnson, R. T. (1989). *Cooperation and competition: Theory and research*. Edina, MN: Interaction Book Company.

Johnson, D. W., & Johnson, R. T. (1995). *Teaching students to be peacemakers* (3rd ed.). Edina, MN: Interaction Book Company.

Johnson, D. W., Johnson, R. T., & Holubec, E. J. (1993). *Cooperation in the Classroom* (6th ed.). Edina, MN: Interaction Book Company.

Johnson-Laird, P. (1983). *Mental models*. Cambridge, MA: Harvard University Press.

Klimoski, R., & Mohammed, S. (1994). Team mental model: Construct or metaphor? *Journal of Management*, *20*, 403–437. doi:10.1016/0149-2063(94)90021-3

Koh, G. C., Khoo, H. E., Wong, M. L., & Koh, D. (2008). The Effects of Problem-based Learning During Medical School on Physician Competency: A Systematic Review. [CMAJ]. *Canadian Medical Association Journal*, *178*(1). doi:10.1503/cmaj.070565

Lajoie, S. P., Lavigne, N. C., Guerrera, C., & Munsie, S. (2001). Constructing Knowledge in the Context of BioWorld. *Instructional Science*, *29*(2), 155–186. doi:10.1023/A:1003996000775

Landauer, T. K., & Dumais, S. T. (1997). A Solution to Plato's Problem: The Latent Semantic Analysis Theory of Acquisition, Induction, and Representation of Knowledge. *Psychological Review*, *104*(2), 211–240. doi:10.1037/0033-295X.104.2.211

Landauer, T. K., Foltz, P. W., & Laham, D. (1998). An Introduction to Latent Semantic Analysis. *Discourse Processes*, *25*, 259–284. doi:10.1080/01638539809545028

Larson, J. R. Jr. (1997). Modeling the entry of shared and unshared information into group discussion: A review and BASIC language computer program. *Small Group Research*, *28*, 454–479. doi:10.1177/1046496497283007

Larson, J. R. Jr. (2007). Deep diversity and strong synergy: Modeling the impact of variability in members' problem-solving strategies on group problem-solving performance. *Small Group Research*, *38*, 413–436. doi:10.1177/1046496407301972

Larson, J. R. Jr, Christensen, C., Franz, T. M., & Abbott, A. S. (1998). Diagnosing groups: The pooling, management, and impact of shared and unshared case information in team-based medical decision making. *Journal of Personality and Social Psychology*, *75*, 93–108. doi:10.1037/0022-3514.75.1.93

Larson, J. R. Jr, & Harmon, V. M. (2007). Recalling shared vs. unshared information mentioned during group discussion: Toward understanding differential repetition rates. *Group Processes & Intergroup Relations*, *10*, 311–322. doi:10.1177/1368430207078692

Lave, J. (1988). *Cognition in Practice*. Cambridge, UK: Cambridge University Press. doi:10.1017/CBO9780511609268

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, UK: Cambridge University Press.

Lave, J., & Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation*. Cambridge, UK: Cambridge University Press.

Levin, J. A., & Kareev, Y. (1980). *Personal computers and education: The challenge to schools. Technical report no. CHIP 98*. La Jolla, CA: Center for Human Information Processing, University of California at San Diego.

Levine, J. M., Resnick, L. B., & Higgins, E. T. (1993). Social foundations of cognition. *Annual Review of Psychology*, *44*, 585–612. doi:10.1146/annurev.ps.44.020193.003101

Liu, M., Williams, D., & Pedersen, S. (2002). Alien Rescue: A Problem-Based Hypermedia Learning Environment for Middle School Science. *Journal of Educational Technology Systems*, *30*(3). doi:10.2190/X531-D6KE-NXVY-N6RE

Marx, R. W., Blumenfeld, P. C., Krajcik, J. S., & Soloway, E. (1997). Enacting project-based science. *The Elementary School Journal*, *97*, 341–358. doi:10.1086/461870

Mathieu, J., Goodwin, G. F., Heffner, T. S., Salas, E., & Cannon-Bowers, J. A. (2000). The influence of shared mental models on team process and performance. *The Journal of Applied Psychology*, *85*(2), 273–283. doi:10.1037/0021-9010.85.2.273

Mcintyre, R. M., & Salas, E. (1995). Measuring and managing for team performance: Emerging principles from complex environments. In Guzzo, R., & Salas, E. (Eds.), *Team effectiveness and decision making in organizations* (pp. 149–203). San Francisco: Jossey-Bass.

Mergendoller, J. R., Maxwell, N. L., & Bellisimo, Y. (2006). The effectiveness of problem-based instruction: a comparative Study of instructional method and student characteristics. *Interdisciplinary Journal of Problem-based Learning*, *1*, 49–69.

Miller, N., Brewer, M. B., & Edwards, K. (1985). Cooperative interaction in desegregated settings: A laboratory analogue. *The Journal of Social Issues*, *41*, 63–79.

Moreland, R. L., & Levine, J. M. (2008). Building bridges to improve theory and research on small groups. In Salas, E., Burke, C. S., & Goodwin, G. F. (Eds.), *Team effectiveness in complex organizations and systems: Cross-disciplinary perspectives and approaches* (pp. 17–38). San Francisco: Jossey-Bass.

Morgan, B. B., Jr., Glickman, A. S., Woodard, E. A., Blaiwes, A. S., & Salas, E. (1986). *Measurement of team behaviors in a Navy environment* (NTSC Tech. Rep. No. 86-014). Orlando, FL: Naval Training Systems Center.

Mullen, B., Brown, R., & Smith, C. (1992). In-group bias as a function of salience, relevance, and status: An integration. *European Journal of Social Psychology*, *22*, 103–122. doi:10.1002/ejsp.2420220202

Munkes, J., & Diehl, M. (2003). Matching or Competition? Performance Comparison Processes in an Idea Generation Task. *Group Processes & Intergroup Relations*, *6*(3), 305–320. doi:10.1177/13684302030063006

Norman, D. A. (1999). Affordance, Conventions, and Design. *Interactions (New York, N.Y.)*, *6*, 38–42. doi:10.1145/301153.301168

Nye, J. L., & Brower, A. M. (Eds.). (1996). *What's social about social cognition? Research on Socially Shared Cognition in Small Groups*. Thousand Oaks, CA: Sage.

Olsen, D. R. (1998). *Developing User Interfaces* (1st ed.). San Francisco: Morgan Kaufmann.

Oshima, J. (1997). Students' construction of scientific explanations in a collaborative hypermedia learning environment. In Hall, N. M. R., & Enyedy, N. (Eds.), *Computer Support for Collaborative Learning '97*. Toronto.

Palincsar, A. S., & Brown, A. L. (1984). Reciprocal teaching of comprehension-fostering and comprehension-monitoring activities. *Cognition and Instruction*, *2*, 117–175.

Perkins, A. (1986). *Knowledge as design*. Hillsdale, NJ: Erlbaum.

Piaget, J. (1954). *The construction of reality in the child*. New York: Basic books. doi:10.1037/11168-000

Puntambekar, S. (1996) *Investigating the effect of a computer tool on students' metacognitive processes*. Unpublished doctoral dissertation, School of Cognitive and computing sciences, University of Sussex, UK.

Qiu, L. (2005). *A web-based architecture and incremental authoring model for interactive learning environments for diagnostic reasoning*. Unpublished doctoral dissertation, Northwestern University, Evanston.

Qiu, L., & Riesbeck, C. K. (2008). Human-in-the-loop: A Feedback-driven Model for Authoring Knowledge-based Interactive Learning Environments. *Journal of Educational Computing Research*, *38*(4), 469–509. doi:10.2190/EC.38.4.e

Reeves, B., & Nass, C. (1996). *The media equation*. Cambridge, MA: SLI Publications, Cambridge University Press.

Resnick, L., Levine, J., & Teasley, S. (Eds.). (1991). *Perspectives on socially shared cognition*. Washington, DC: American Psychological Association. doi:10.1037/10096-000

Resnick, L. B. (1987). *Education and learning to think*. Washington, DC: National Academy Press.

Roschelle, J., & Teasley, S. (1995). The construction of shared knowledge in collaborative problem solving. In O'Malley, C. (Ed.), *Computer-supported collaborative learning* (pp. 69–197). Berlin, Germany: Springer Verlag.

Rouse, W. B., & Morris, N. M. (1986). On looking into the black box: Prospects and limits in the search for mental models. *Psychological Bulletin*, *100*, 349–363. doi:10.1037/0033-2909.100.3.349

Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. In Smith, B. (Ed.), *Liberal education in a knowledge society* (pp. 76–98).

Scardamalia, M. (2003). Knowledge building. *Journal of Distance Education*, *17*(S3), 10–14.

Scardamalia, M., & Bereiter, C. (1991). Higher Levels of Agency for Children in Knowledge Building: A Challenge for the Design of New Knowledge Media. *Journal of the Learning Sciences*, *1*(1), 37–68. doi:10.1207/s15327809jls0101_3

Scardamalia, M., & Bereiter, C. (1994). Computer support for knowledge building communities. *Journal of the Learning Sciences*, *3*(3), 265–283. doi:10.1207/s15327809jls0303_3

Scardamalia, M., Bereiter, C., & Lamon, M. (1994). The CSILE project: Trying to bring

Schank, R., Fano, A., Bell, B., & Jona, M. (1993). The design of goal-based scenarios. *Journal of the Learning Sciences*, *3*, 305–345. doi:10.1207/s15327809jls0304_2

Schank, R., & Neaman, A. (2001). Motivation and Failure in Educational Simulation Design. In Forbus, K. D., & Feltovich, P. J. (Eds.), *Smart Machines in Education* (pp. 99–144). Menlo Park, CA: AAAI Press/MIT Press.

Schofield, J. W. (1995). *Computers and classroom culture*. New York: Cambridge University Press.

Schon, D. A. (1983). *The Reflective Practitioner: How Professionals Think in Action*. NY: Basic Books.

Schon, D. A. (1987). *Educating the Reflective Practitioner*. San Francisco, CA: Jossey-Bass.

Schopler, J., & Insko, C. A. (1992). The discontinuity effect in interpersonal and intergroup relations: Generality and mediation. In Stroebe, W., & Hewstone, M. (Eds.), *European review of social psychology* (pp. 121–151). Chichester, UK: Wiley.

Slavin, R. E. (1990). *Cooperative learning: Theory, research, and practice*. Englewood Cliffs, NJ: Prentice Hall.

Slavin, R. E. (1991). *Student team learning: A practical guide to cooperative* (3rd ed.). Washington, DC: National Education Association of the United States.

Slavin, R. E. (1996). *Education for all*. Exton, PA: Swets & Zeitlinger Publishers.

Stahl, G., Koschmann, T., & Suthers, D. (2006). Computer-supported collaborative learning. In Sawyer, R. K. (Ed.), *Cambridge handbook of the learning sciences*. Cambridge, UK: Cambridge University Press.

Stevens, R. J., & Slavin, R. E. (1995). The cooperative elementary school: Effects on students' achievement, attitudes, and social relations. *American Educational Research Journal*, *32*, 321–351.

Suthers, D., Connelly, J., Lesgold, A., Paolucci, M., Toth, E., Toth, J., & Weiner, A. (2001). Representational and Advisory Guidance for Students Learning Scientific Inquiry. In *Forbus, K. D., and Feltovich, P. J. (2001). Smart machines in education: The coming revolution in educational technology* (pp. 7–35). Menlo Park, CA: AAAI/Mit Press.

Suthers, D., Connelly, J., Lesgold, A., Paolucci, M., Toth, E., Toth, J., & Weiner, A. (2001). Representational and Advisory Guidance for Students Learning Scientific Inquiry. In Forbus, K. D., & Feltovich, P. J. (Eds.), *Smart machines in education: The coming revolution in educational technology* (pp. 7–35). Menlo Park, CA: AAAI/MIT Press.

Suthers, D. D., & Hundhausen, C. (2003). An experimental study of the effects of representational guidance on collaborative learning. *Journal of the Learning Sciences*, *12*(2), 183–219. doi:10.1207/S15327809JLS1202_2

Suthers, D. D., Vatrapu, R., Medina, R., Joseph, S., & Dwyer, N. (2007). Conceptual representations enhance knowledge construction in asynchronous collaboration. In C. Chinn, G. Erkens & S. Puntambekar (Eds.), *The Computer Supported Collaborative Learning (CSCL) Conference 2007* (pp. 704-713). New Brunswick: International Society of the Learning Sciences.

Suthers, D. D., Vatrapu, R., Medina, R., Joseph, S., & Dwyer, N. (2008). Beyond Threaded Discussion: Representational Guidance in Asynchronous Collaborative Learning Environments. *Computers & Education*, *50*(4), 1103–1127. doi:10.1016/j.compedu.2006.10.007

Tajfel, H., & Turner, J. C. (1986). The social identity theory of intergroup behavior. In Worchel, S., & Austin, W. (Eds.), *Psychology of intergroup relations* (pp. 7–24). Chicago, IL: Nelson-Hall.

the classroom into World 3. In K. McGilley (Eds.), *Classroom lessons: Integrating*

Thompson, L. (1998). *The mind and heart of the negotiator*. Upper Saddle River, NJ: Prentice Hall.

Turner, J. C., Hogg, M., Oakes, P., Reicher, S., & Wetherell, M. (1987). *Rediscovering the social group: A self-categorization theory*. Oxford, UK: Basil Blackwell.

Valacich, J. S., Dennis, A. R., & Nunamaker, J. F. (1992). Group size and anonymity effects on computer-mediated idea generation. *Small Group Research*, *23*(1), 49–73. doi:10.1177/1046496492231004

Virvou, M., Katsionis, G., & Konstantinos, M. (2005). Combining software games with education and evaluation of its educational effectiveness. *Educational Technology & Society*, *8*(2), 54–65.

Webb, N. (1985). Student interaction and learning in small groups: A research summary. In Slavin, R., Sharan, S., Kagan, S., Hertz-Lazarowitz, R., Webb, C., & Schmuck, R. (Eds.), *Learning to cooperate, cooperating to learn* (pp. 148–172). New York: Plenum.

Wenger, E. (1987). *Artificial Intelligence and Tutoring Systems: Computational and Cognitive Approaches to the Communication of Knowledge*. Los Altos, CA: Morgan Kaufmann Publishers, Inc.

Wilson, J. R., & Rutherford, A. (1989). Mental models: Theory and application in human factors. *Human Factors*, *31*, 617–634.

Wittenbaum, G. M., & Park, E. S. (2001). The collective preference for shared information. *Current Directions in Psychological Science*, *10*, 70–73. doi:10.1111/1467-8721.00118

Woolf, B. P., & Cunningham, P. A. (1987). Multiple knowledge sources in intelligent teaching systems. *IEEE Expert*, *2*, 41–54. doi:10.1109/MEX.1987.4307063

ADDITIONAL READING

Bereiter, C. (2002). *Education and mind in the knowledge age*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (1999). *How people learn: Brain, Mind, Experience, and School*. Washington, DC: National Academy Press.

Bromme, R., Hesse, F. W., & Spada, H. (Eds.). (2005). Barriers and biases in computer-mediated knowledge communication, and how they may be overcome. In P. Dillenbourg (Ed.), Computer-supported collaborative learning book series. New York: Springer.

Bruffee, K. (1993). *Collaborative learning*. Baltimore, MD: Johns Hopkins University Press.

Cannon-Bowers, J. A., Salas, E., & Converse, S. A. (1993). Shared mental models in expert team decision making. In Castellan, N. J. Jr., (Ed.), *Current issues in individual and group decision making* (pp. 221–246). Hillsdale, N J: Erlbaum.

Collins, A., & Brown, J. (1988). The computer as a tool for learning through reflection. In Mandl, H., & Lesgold, A. (Eds.), *Learning issues for intelligent tutoring systems*. New York: Springer Verlag.

Gaertner, S. L., Dovidio, J. F., Anastasio, P., Bachman, B. A., & Rust, M. (1993). The Common Ingroup Identity Model: Recategorization and the reduction of intergroup bias. In Stroebe, W., & Hewstone, M. (Eds.), *European review of social psychology* (*Vol. 4*, p. l-26). Chichester, UK: Wiley.

Hmelo-Silver, C. E., & Barrows, H. S. (2006). Goals and strategies of a problem-based learning facilitator. *Interdisciplinary Journal of Problem-based Learning*, *1*, 21–39.

Johnson, D. W., & Johnson, R. T. (1989). *Cooperation and competition: Theory and research*. Edina, MN: Interaction Book Company.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, UK: Cambridge University Press.

Mcintyre, R. M., & Salas, E. (1995). Measuring and managing for team performance: Emerging principles from complex environments. In Guzzo, R., & Salas, E. (Eds.), *Team effectiveness and decision making in organizations* (pp. 149–203). San Francisco: Jossey-Bass.

Moreland, R. L., & Levine, J. M. (2008). Building bridges to improve theory and research on small groups. In Salas, E., Burke, C. S., & Goodwin, G. F. (Eds.), *Team effectiveness in complex organizations and systems: Cross-disciplinary perspectives and approaches* (pp. 17–38). San Francisco: Jossey-Bass.

Newman, D., Griffin, P., & Cole, M. (1989). *The construction zone: Working for cognitive change in schools*. Cambridge, UK: Cambridge University Press.

Norman, D. A. (1999). Affordance, Conventions, and Design. *Interactions (New York, N.Y.)*, *6*, 38–42. doi:10.1145/301153.301168

Nye, J. L., & Brower, A. M. (Eds.). (1996). *What's social about social cognition?: Research on Socially Shared Cognition in Small Groups*. Thousand Oaks, CA: Sage.

O'Malley, C. (1995). *Computer supported collaborative learning*. Berlin, Germany: Springer Verlag.

Reeves, B., & Nass, C. (1996). *The media equation*. Cambridge: SLI Publications, Cambridge University Press.

Resnick, L. B. (1987). *Education and learning to think*. Washington, DC: National Academy Press.

Roschelle, J., & Teasley, S. (1995). The construction of shared knowledge in collaborative problem solving. In O'Malley, C. (Ed.), *Computer-supported collaborative learning* (pp. 69–197). Berlin, Germany: Springer Verlag.

Schank, R., & Neaman, A. (2001). Motivation and Failure in Educational Simulation Design. In Forbus, K. D., & Feltovich, P. J. (Eds.), *Smart Machines in Education* (pp. 99–144). Menlo Park, CA: AAAI Press/MIT Press.

Schopler, J., & Insko, C. A. (1992). The discontinuity effect in interpersonal and intergroup relations: Generality and mediation. In Stroebe, W., & Hewstone, M. (Eds.), *European review of social psychology* (pp. 121–151). Chichester, UK: Wiley.

Stahl, G., Koschmann, T., & Suthers, D. (2006). Computer-supported collaborative learning. In Sawyer, R. K. (Ed.), *Cambridge handbook of the learning sciences*. Cambridge, UK: Cambridge University Press.

Thompson, L. (1998). *The mind and heart of the negotiator*. Upper Saddle River, NJ: Prentice Hall.

Webb, N. (1985). Student interaction and learning in small groups: A research summary. In Slavin, R., Sharan, S., Kagan, S., Hertz-Lazarowitz, R., Webb, C., & Schmuck, R. (Eds.), *Learning to cooperate, cooperating to learn* (pp. 148–172). New York: Plenum.

Wenger, E. (1987). *Artificial Intelligence and Tutoring Systems: Computational and Cognitive Approaches to the Communication of Knowledge*. Los Altos, CA: Morgan Kaufmann Publishers, Inc.

Wittenbaum, G. M., & Park, E. S. (2001). The collective preference for shared information. *Current Directions in Psychological Science*, *10*, 70–73. doi:10.1111/1467-8721.00118

KEY TERMS AND DEFINITIONS

Collaborative Learning: A pedagogical approach that embeds learning in collaborative activities where students work in teams to accomplish a common goal.

Collaboration Technologies: Computer technologies designed to facilitate group collaboration.

Educational Technology: Technologies designed to facilitate education.

Goal-Based Learning: A pedagogical approach that embeds learning in the pursuit of a specific goal.

Learning-by-Doing: A form of learning that obtains new knowledge through the practical doing of things.

Problem-Based Learning: A pedagogical approach that situates learning in the process of solving complex and ill-structured realistic problems.

Web-Based Learning: A pedagogical approach that uses web-based tools to facilitate learning.