Designing Effective Science Inquiry in Text-Based Computer-Supported Collaborative Learning Environments

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Introduction

Reform movements and standards call for inquiry learning in the classroom (AAAS, 1993; NRC, 1996). Implementing inquiry learning, however, has proven challenging (Krajcik, Blumenfeld, Marx, & Soloway, 1994; Ladewski, Krajcik, & Harvey, 1994; Marx, Blumenfeld, Krajcik, Blunk, Crawford, Kelly, & Meyer, 1994). Text-based computer-supported collaborative learning environments (text-based CSCL) offer great potential for supporting students and teachers in inquiry learning. We first present an overview of inquiry learning and the challenges to implementing inquiry in the classroom. We then propose a set of design guidelines for educators, administrators, and curriculum developers who are designing or choosing text-based CSCL environments to support inquiry.

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International Journal of Educational Policy, Research, & Practice, Volume 4, Number 1, Spring 2003
ISSN 1528-3534;

Scientific Inquiry

Scientific inquiry involves knowledge about "the methods employed in the collection, analysis, synthesis, and evaluation of evidence" and "why science believes what it does and how science has come to think that way" (Duschl, 1990). The process of building scientific knowledge by inquiry learning is complex, but some commonalties exist across disciplines (Rutherford & Ahlgren, 1990). What counts as evidence varies, but evidence is central to all inquiry. Hypotheses define what is expected to happen during an investigation. Theories and models account for, explain, and predict the results of an investigation. Across disciplines, scientific concepts, or regularities in the data, do not simply emerge from data, and Rutherford and Ahlgren (1990) stress the importance of creativity in constructing explanations. Explanatory mechanisms, models, and theories are constructed through collaboration and insight to account for observations. Perkins explains that models "connect abstract physical principles to concrete experienced manifestations of them, so that the import of the principles will be understood in an intuitive way" (Perkins, 1986). Explanatory mechanisms change over time to accommodate new evidence as scientists work with one another, often through the forum of scholarly texts and meetings. Ultimately, patterns of logical and hypothetico-deductive reasoning connect these components through scientific argumentation.

Challenges to Students and Teachers

The traditional focus on inquiry in science education goes back more than a century (e.g., Bruner, 1960; Dewey, 1910; Gagne, 1963). Inquiry learning in the classroom involves the process of acquiring knowledge and skills by addressing the problems of a domain at increasing levels of complexity. Inquiry learning is important because inquiry and argumentation are genres of discourse crucial in the practice of science (Driver, Newton, & Osbourne, 2000; Kuhn, 1993; Lemke, 1990; Siegel, 1995; Toulmin, 1958) and much of science involves dialectical and rhetorical argumentation (Latour & Woolgar, 1986; Longino, 1994). In this vein, several researchers have shown that students' participation in discourse of learning communities paralleling that of expert communities is key to successful science education (e.g., Lemke, 1990; Roseberry, Warren, & Conant, 1992; Schauble, Glaser, Duschl, Schulze, & John, 1995).

Inquiry learning is challenging for both students and teachers. The general scientific content knowledge that plays an important role in inquiry has long been taught as facts and principles, but the inquiry process skills themselves are often lacking (Gagne, 1963). Inquiry typically requires social supports, takes place as an enculturalization into a community of experts, and includes the development of norms and general interest within a domain (cf. Lave & Wenger, 1992; Scardemalia & Bereiter, 1996). This scientific discourse requires making private claims of individual students or small groups public to larger groups of students for the construction of arguments (Bell, 1997; Hogan, 1999). Students also need to create and appropriate criteria and skills for evaluating arguments as well as to understand the epistemological and social processes in which knowledge claims are shaped and transformed (e.g., Driver, Leach, Millar, & Scott, 1996; White & Fredericksen, 1998).

While the literature shows that students can improve their inquiry skills through practice (Finkel & Stewart, 1994; Krajcik, Blumenfeld, Marx, Bass, Fredericks, & Soloway, 1996; Roth, 1993a, 1993b), building and testing theories and hypotheses are very difficult for students. Students can develop more detailed designs as the year progresses, but students' designs often do not adequately address the questions they pose (Krajcik, Blumenfeld, Marx, & Soloway, 1994). In terms of developing multiple alternative models, assessing these models, and accepting one final model, students engage in these processes in varying degrees and with varying success depending on the process, the nature of the problem, and the time allotted to the process (Finkel & Stewart, 1994). Students exhibit difficulty in using all available evidence as the basis for conclusions and decisions (Hancock, Kaput, & Goldsmith, 1992; Krajcik, Blumenfeld, Marx, Bass, Fredricks, & Soloway, 1996; Schauble, Glaser, Duschl, Schulze, & John, 1995). Students (as well as scientists) also sometimes ignore, reject, exclude, or reinterpret anomalous data, depending on the situation (Chinn & Brewer, 1993). As part of conducting inquiry, therefore, students essentially need scaffolding to: define a problem area, construct a systematic method to address the problem, construct and revise models and theories based on evidence to explain phenomenon or make predictions, and build and evaluate arguments using empirical evidence or models to justify a claim or make a decision.

Teachers face a host of problems in integrating inquiry into their practices (Krajcik, Blumenfeld, Marx, & Soloway, 1994; Ladewski, Krajcik, & Harvey, 1994; Marx , Blumenfeld, Krajcik, Blunk, Crawford, Kelly, & Meyer, 1994). An account of these challenges was documented by Krajcik. Blumenfeld, Marx, and Soloway (1994). These challenges include: (1) building instruction around authentic problems that are contextualized, important, complex, meaningful, and interesting; (2) scaffolding student understanding through active construction, multiple representations, application of information, situated contexts, and strategic thinking; (3) creating a community of learners including collaboration, social context, negotiated meaning, and distributed expertise; and (4) integrating cognitive technological tools into the curriculum to support inquiry. In our discussion, we use these challenges as the analytical lens for our proposed set of guidelines for educators, administrators, and curriculum developers who are designing or choosing text-based CSCL environments to support inquiry.

Technology and Collaboration To Support Science Inquiry Learning

Technology has been harnessed to create structured environments to support inquiry learning (e.g., Edelson, Gordon, & Pea, 1999; Linn, 2000; Scardamalia & Bereiter, 1996). Asynchronous text-based environments in which discussions are held and community is created have been shown effective (Salomon, 2000; Collison, Elbaum, Haavind, & Tinker, 2000). Scardemalia and Bereiter (1996) made important contributions to this enterprise with CSILE (now known as Knowledge Forum), wherein students are able to use the technology to share their ideas with one another and to receive feedback, working as a group to build their ideas. Text-based CSCL environments can support student participation in discussions by achieving much higher participation rates and gender equity than evidence in traditional classroom discussions (Hsi, 1997). The importance of social relevance to the success of these discussions has also been demonstrated (Hoadley & Linn, 2000). Other important work has focused specifically on discourse processes during computer mediated communication (e.g., Goldman, Duschl, Williams, & Ellenbogen, in press) and on supporting argumentation in particular (e.g., Duschl, Ellenbogen, & Erduran, 1999).

Collaborative inquiry learning is based on the assumption that discourse fosters motivational as well as cognitive processes vital to learning. Learners may aid one another motivationally to attempt to reach individual and joint learning goals. This motivational perspective to collaborative learning stresses the idea that learners should either perceive individual success as dependent on the success of the group (Slavin, 1996) or support each other due to social cohesion (Cohen, 1994). Cognitive theories point out effects of collaborative learning on mental processing. In successful collaborative learning, multiple perspectives are made visible (Mandl, Gruber, & Renkl, 1996), learners outline their mental models in an active manner, learners can evaluate false inferences (Slavin, 1996), and learners can adjust models by processes of refinement and restructuring through externalization (Leitão, 2000) or by the guidance of a more competent peer (Vygotsky, 1978). Assuming that students' discourse activities are learning phenomena as well as learning promoters (Leitão, 2000; Vygotsky, 1978), improving the quantity and quality of the discourse during inquiry can be considered crucial to enhancing the inquiry learning process.

Text-based CSCL offers several potential advantages in supporting collaborative inquiry learning. As stated earlier, one advantage involves universal participation by all students rather than the much smaller percentage of students who are able to participate in most in-class face to face interactions. Text-based communication may also facilitate discourse in inquiry learning because learners have more time to formulate well thought out contributions. Furthermore, processes of collaborative science inquiry can be reconstructed as the discourse is saved and stays visible (e.g., in electronic bulletin boards). Text-based CSCL environments also offer a natural choice because the textual medium is itself an asset. Text-based CSCL allows students to participate directly in the linguistic medium and format of scientific discourse while engaging in inquiry practices such as argumentation. In this manner, text-based CSCL environments can simultaneously support students in the same class who are at multiple levels of linguistic and scientific proficiency as they collaborate in the representations, discourse, and processes of inquiry.

Several studies show, however, that learning groups do not necessarily work well on their own and that they do not necessarily improve when collaborating in text-based CSCL environments (e.g., Salomon & Globerson, 1989; Fischer & Mandl, 2001; Hara & Kling, 1999). One problem is that learners in text-based CSCL environments typically lack immediate feedback. Thus, learners often fail to evaluate and fully understand online material on which they base their inquiry (Jucks, 2001). A second problem is that learners in CSCL environments may not engage effectively in the collaborative interactions of scientific inquiry. Learners jump to conclusions and hardly explain or justify utterances (Eichinger, Anderson, Palinscar, & David, 1991; Forman, 1992). Learners may also discard ideas of learning partners based on status rather than scientific argumentation (Coleman, 1995; Kuhn, Shaw, & Felton, 1997). In this way, computer-supported inquiry learning in groups may show poor or unequal participation and learning outcomes (e.g., Weinberger & Mandl, 2001).

While text-based CSCL has great potential to support inquiry in the classroom, this potential is therefore not always realized. In the following sections we present and explore a set of strategies to minimize the potential negative traits of text-based CSCL while taking advantage of its affordances to support inquiry learning.

Design Guidelines for Supporting Science Inquiry Learning through Text-Based CSCL

Dillenbourg (2002) distinguishes two different ways to facilitate collaborative learning in general. On one hand, teachers can indirectly influence the effectiveness of collaboration by arranging basic conditions like the group size, the group task, or the learners' cooperation competencies prior to the actual collaborative inquiry learning. The classic cooperation script (Dansereau, 1988), for example, involves more time for prior training than for an actual collaborative learning session. The high cost in terms of effort and instructional time inherent in prior training, therefore, may argue for a more process-oriented approach.

Process-oriented approaches directly influence the interactions of group members by giving appropriate instructions during the collaborative learning phase and may be more feasible for implementation (cf. Weinberger, Reiserer, Ertl, Fischer, & Mandl, in press). Several approaches to structuring the interaction of learners have been developed (e.g., scripted co-operation, O'Donnell, 1999). Typically, interaction has been structured by sequencing particular collaborative activities and by assigning roles to the various participants of each group (Cohen, 1994). Structuring the discourse interaction of learners in text-based CSCL may be the most direct way to influence the quality of collaborative inquiry learning.

Our goal is to apply a process-oriented approach to better support inquiry through CSCL environments. As discussed in earlier sections, inquiry learning includes the collaborative exploration of complex material and may be characterized by a high degree of freedom for the learners. It seems likely that learners may not comprehend the complex learning material and/or may not choose to engage in interactions regarded as beneficial to learning. Therefore, we first present strategies focusing on (a) incorporating prompts within the structure of CSCL environments to organize interactions, (b) structuring the activities to elicit, share, and contrast students' ideas, and (c) facilitating and moderating interactions to focus the learners. We then go on to outline more general strategies focusing on (d) representing complex subject matter and (e) ensuring and assessing comprehensibility of materials.

Structure Activity through Prompt-Based Scripts

Supports can be built within learning environments to structure learners' discourse and to guide users through a certain series of activities in collaborative science inquiry (Baker & Lund, 1997; Jonassen & Remidez, 2002; King, 1998; Scardemalia & Bereiter, 1996). Structuring interaction with content-specific and interaction-oriented scripted prompts built into the software environment to support students has shown particular promise for improving collaborative reflection on relevant concepts (Weinberger, Fischer, & Mandl, 2001). Prompt-based *content-specific scripts* help learners to consider relevant concepts while prompt-based *interaction-oriented scripts* foster deep reflection. Cooperative scripts in traditional settings often entail significant work by teachers to model problem solutions or to train students in advance of any form of cooperation. In contrast, prompt-based scripts can achieve these goals and substitute for extensive training and adaptive feedback by face-to-face experts (Weinberger, Fischer, & Mandl, 2001).

Prompt-based content-specific scripts. Inquiry involves multiple concepts, data samples, and interpretations. Since learners often discuss at a superficial level and digress or argue about isolated and naive concepts, interventions to pre-structure the content offer great promise. Pre-structuring the content does not mean, however, adding content or portraying the content in more detail. Rather, contextual supports are described as a kind of scaffolding given to learners by experts in the domain to support them in taking all relevant concepts into account (Collins, Brown, & Newmann, 1989; Davis & Linn, 2000). In text-based CSCL, content-specific scripts can be prompts that pre-structure the input window (see Figure 1). In other words, the learners' message may already contain prompts. These content-specific prompts are questions (Figure 1 involves the theory of attribution by Weiner, 1985) and are aimed at supporting the learners' identification of relevant information. Thus, the students' task is basically to elaborate jointly on the given prompts.

Prompt-based interaction-oriented scripts. Apart from the content-oriented aspect of cognitive responses, an interaction-oriented component is also relevant for learning and is critical to our process-based approach to supporting inquiry learning. As learners' spontaneous cooperation strategies often prove sub-optimal, educational researchers (e.g., O'Donnell, 1999) have pre-structured the learning discourse by means of scripts that provide learners with roles and encourage them to perform particular interactions at a specified time. Typically, an interaction-oriented script prescribes sub-tasks in a particular chronology and assigns two roles (e.g., "analyst" and "constructive critic") that the learners undertake interchangeably. In text-based CSCL, a prompt-based interaction-oriented script can be automatically inserted into the messages to help learners successfully take over their roles in the inquiry process (see Figure 1). The students can be guided through all sub-tasks to play the individual roles alternately. The prompted interaction-

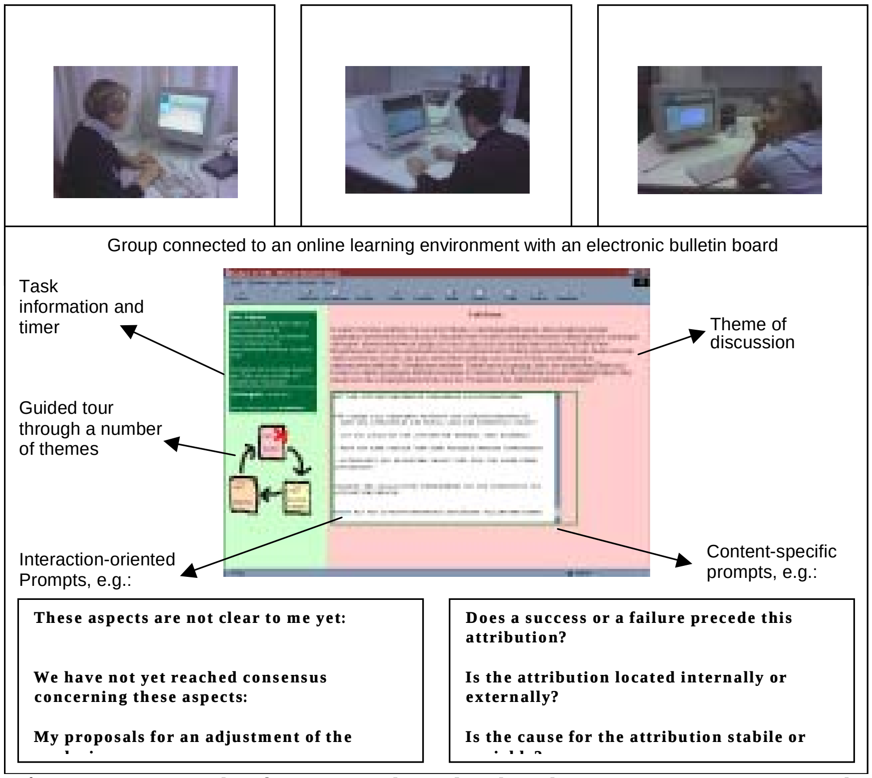

Figure 1. *Example of a prompt-based online learning environment. The upper section of the figure shows three students in separate rooms jointly analyzing a learning case of attribution theory via an electronic bulletin board that is shown in the lower section of the figure.*

oriented script encourages learners to participate equally in recursive and coherent interactions as they critically refine concepts.

Empirical studies show that these content-specific and interaction-oriented scripts can improve the quality of science inquiry discourse and knowledge transfer (Weinberger, Fischer, & Mandl, 2001). Learners who are supported by interaction-oriented scripts appear to be encouraged to confront their ideas with those of their partners, to reflect on the differences of perspectives, and sometimes to modify their initial points of view. Content-specific scripts help learners in the processes of science inquiry — learners who are supported by content-specific scripts apply knowledge more adequately. Content-specific scripts may substitute the need for learners to develop an internal model of the contents. With respect to knowledge acquisition, however, content-specific scripts have proven less beneficial to knowledge acquisition than interaction-oriented scripts (Weinberger et al., 2001). Designers of instructional supports must therefore consider the degree to which scripts maximize the advantages of CSCL and the degree to which they activate learners' reflective thinking rather than simply ease the learning task (Reiser, 2002).

To further develop scripts to support inquiry learning in text-based CSCL, we need to keep in mind that scripts should not substitute for important learning processes but rather should foster students' endeavors at collaborative inquiry. Content-specific support must therefore be carefully implemented. One possibility for structuring content is to distribute responsibility for particular content over various members of the learning group (e.g., the jigsaw-method by Aronson, Blaney, Stephan, Silkes, & Snapp, 1978). One important aspect of distributed resources is that learners must impart their knowledge to their learning partners in order to reach a solution. Employing distributed roles is a major characteristic of successful interaction-oriented scripts. A division of labor with regard to content might be helpful as well.

A further concern of prompt-based scripts involves their context-dependent implementation. Guidelines must be developed pursuant to (1) who may profit most from prompt-based scripts, and (2) how scripts need to be adapted for longer periods of collaborative learning (e.g., in virtual seminars). In terms of who may profit most from prompt-based scripts, some researchers suggest that personality traits like anxiety and openness to ideas may influence the quality of online discourse, and traits can be mitigated by prompts to support all students more fully (Nussbaum, Hartley, Sinatra, Reynolds, & Bendixen, 2002). Others point to the fact that the success of scripts may depend on matching learners' prior knowledge with the degree of granularity of the script (Cohen, 1994). While learners with little or no prior knowledge may benefit from detailed scripts of high granularity, advanced learners may be hampered by detailed scripts and not accept instructions of scripts at all. Advanced learners appear to be more successful with rough instructions and low granularity of the scripts (e.g., the distribution of roles).

In terms of adapting scripts for longer periods of interaction, it does not always make sense for learners to follow explicit instructions. First of all, the level of expertise of the learners should improve by dealing with the learning environment. Therefore, the necessary granularity of the scripts needs to be adapted over time. Secondly, learners should finally internalize the strategies suggested by the scripts. Therefore, the fading of support must be an integral part of these kinds of scaffolding (Collins, Brown, & Newmann, 1989). Otherwise, learners may display the activities suggested by the script but not actually learn them. Thirdly, learners may reinterpret prompts over time and use them in unintended ways. Pre-structuring by prompts cannot adapt to momentary needs. This argues for local rather than general prompts. Designers of learning environments should therefore consider fitting local prompts to the individual tasks of the learners. This may include the successive reduction of prompt-based scripts.

Engage Students in Scientific Discourse through Eliciting, Sharing, and Contrasting Their Ideas with One Another

In addition to structuring activity through prompt-based scripts, we can also support collaborative inquiry through an activity structure that elicits, shares, and contrasts students' own ideas to engage them in the discourse of science argumentation and inquiry. As discussed earlier, learning is a social as well as cognitive enterprise as shown by Vygotsky (1978) and others (e.g., Bransford, Brown, & Cocking, 1999; Saxe & Guberman, 1998; Tudge & Rogoff, 1989). The way a community is structured has great bearing on the quality of learning that occurs within that community (e.g., Brown & Campione, 1994).

Optimally, these communities should be configured around authentic practices (e.g., Brown, Collins, & Duguid, 1989; Collins et al., 1989; Lave & Wenger, 1992). Contrasting multiple students' perspectives can encourage a student to clarify his or her own statements while considering the relevance of other students' opinions (diSessa & Minstrell, 1998; Chi, Lewis, Reimann, & Glaser, 1989). This perspective-taking is important because: (a) students have trouble supporting their ideas with evidence, (b) students don't have shared criteria for evaluating explanations, (c) clarification often involves contrasting perspectives, and (d) clarification also involves developing a repertoire of models (Cuthbert, Clark, & Linn, 2002). By increasing personal relevance around the process of contrasting student perspectives, we create relationships that elicit students' conceptual resources to refine the group's ideas. In addition, this process helps induct students into the discourse of science not simply by studying science but by actually engaging and participating in it.

An example of this strategy involves personally-seeded discussions (Clark, in press). Following the predictions and data gathering in a hands-on lab, students create principles to describe patterns in their data using a web-based principle builder that is essentially a series of pull-down menus allowing students to string together phrases to construct a principle mirroring principles that they had already written in their notes (see Figure 2). The student-constructed principles appear as the seed comments in the online discussions. To help students develop a repertoire of models, the text-based CSCL software automatically groups

Figure 2. *The Discussion System for Personally-Seeded Discussions*

students in electronic discussions with peers who have different perspectives. The groups critique and discuss these principles, working toward consensus. The discussion develops around the different perspectives represented in the seed comments by each student group, ideally through a process of comparison, clarification, and justification (see Figure 3).

Structures like personally-seeded discussions support engagement in actual scientific inquiry practices as the students collaboratively construct explanations for scientific observations. Students work to clarify and justify their own scientific principles, comparing and contrasting them with other students' principles. This approach takes advantage of findings on the importance of personal relevance (Hoadley & Linn, 2000). Thinking is made "visible" for students as they elaborate upon and justify their ideas. By having students explain and defend their own principles, students not only take an interest in their own ideas, but also take interest in responding to and critiquing the other ideas in the discussion. The role of the teacher shifts from presenting alternative views to helping students understand those alternatives, ask for clarification, and refine their own ideas. This type of activity structure therefore facilitates

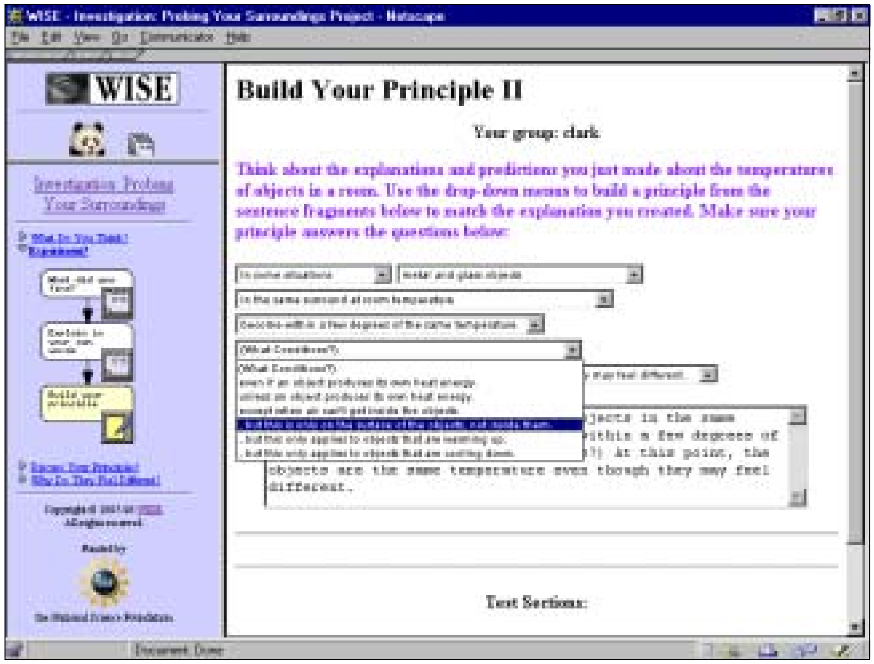

Figure 3. Students use the principle-builder to construct scientific principles that become initial discussion comments.

online discussions where students successfully share their conceptual resources in the common task of refining their own ideas.

To be effective, activities with this type of structure need clearly to specify and scaffold students in effectively critiquing one another's principles. In particular, students struggle with properly warranting their assertions and critiques with evidence from the classroom or personal experience (Bell, 1997). Students all too easily dismiss or insult other students' principles without providing rationale or warrants. One useful approach is to have students brainstorm situations or cases where a principle would not be "true" based on evidence from class or their own experiences.

Similarly, the terms and phrases within each pull down menu (or other interface) require iterative clarification and simplification because overwhelming numbers of permutations confuse students and students often need help understanding the role and concept of a "principle" to describe their data. Alternatively, the teacher could assign students to groups and students could simply "cut-and-paste" their principles into the discussions as the seed comments. This second approach is less complex to institute but faces other challenges. "Cutting" and "pasting" would allow the students more flexibility in constructing their principles, but would not allow the computer to group the students in terms of different principles and might not constrain students sufficiently to allow them to compare their principles on the salient issues.

Finally, the teacher also needs to pay attention to what is happening in the discussions because particularly persuasive students can often end up convincing their group of a non-normative explanation for the data. A whole class discussion of the outcomes from each group is a critical follow-up for online personally-seeded discussions. Furthermore, significant time in the lesson plan needs to be allocated because students require more time to make productive comments when critiquing each others' ideas than when the students are simply commenting on generic seed comments.

Scaffold the Interaction with a Moderator

A moderator of a text-based CSCL environment can significantly enhance a process-oriented approach to scaffolding collaborative inquiry learning through timely and purposeful intervention within the participants' threaded dialogues. Research shows that text-based CSCL environments that are scheduled, well-designed, and moderated by trained facilitators offer a rich learning experience and encourage participants through online discourse to develop inquiry strategies (Collison et al., 2000; Harasim, Hiltz, Teles, & Turoff, 1995; Tinker & Haavind, 1996). The moderator should encourage, synthesizes and challenge the participants to think deeply about their beliefs and knowledge of inquiry based learning. *Facilitating Online Learning* (Collison et al., 2000) describes several critical strategies moderators of online learning environments may use to focus and deepen participants' dialogue. Unfortunately, well designed text-based CSCL environments with organized assignments, schedules, threaded discussions, and posting areas often run awry when moderators derail productive discourse, take over the discussion, or "say" too little and appear to be nonexistent. Good moderating includes techniques that generate dialogue, disentangle tensions, and encourage participants to build on one another's comments.

The moderator plays a critical role in facilitating participants' online learning. A moderator who interjects either too frequently or too infrequently can limit the development of participants' dialogue and learning from one another. A moderator can, however, deeply impact the direction and depth of the participants' discourse, helping the participants to construct deeper understandings. A moderator can use a number of critical thinking strategies to promote this deeper understanding. These critical thinking strategies can be divided into two categories: strategies that *sharpen the focus* of a dialogue and strategies that *deepen dialogue*. Strategies to sharpen the focus include (1) identifying the direction, (2) sorting ideas for relevance, and (3) focusing the discussion on key points. Strategies to deepen the dialogue include (1) full spectrum questioning, (2) making connections, and (3) honoring multiple perspectives. Collison and colleagues (2000) further elaborate on these strategies, which are summarized below.

Sharpen the focus. Three strategies may be used to help participants sharpen the focus of their dialogue. First, the moderator helps participants identify the direction of the dialogue by highlighting passages and posts that respond to the goals of the particular activity. Identifying direction helps participants refocus or redirect dialogue that veers from the main topic. The moderator selects or highlights pieces of participants' dialogue that keep the discussion moving toward the intended goals. Second, the moderator can sort participants' ideas for relevance. This open and explicit strategy helps participants identify weights to ideas and recognize that all ideas are not of equal value. This strategy helps participants recognize tangents and digressions that may be appealing but do not move the understanding forward. Third, the moderator illustrates key points made by the participants that highlight essential concepts, tensions, and even critical ideas left out of the discussion. It is important that the moderator leaves out assessments of accuracy and completeness and instead creates an environment that encourages participants to reflect and discuss these issues. In this way, moderators provide interaction related prompts similar to those provided through interaction oriented scripts.

Deepen the dialogue. Three strategies encourage participants to deepen their dialogue. First, the moderator can employ "full spectrum questioning," the "who, what, when, where, and why" questions that promote examination of participants' thoughts, beliefs and hypotheses. Full spectrum questions work to clarify meaning, explore assumptions, identify relationships and consider next steps. Second, the moderator can deepen understanding by facilitating participants in making connections between ideas, concepts, or contexts. The moderator may set up alternative interpretations, scenarios, or analogies and invite participants to compare, contrast and build relationships. Finally, the strategy of honoring multiple perspectives encourages participants to detach themselves from particular beliefs or assumptions and to consider other viewpoints or rationales. The moderator may describe a variety of approaches to a problem and encourage participants to reflect and comment on the different methodologies and perspectives.

Represent Complex Subject Matter through Multiple Supplemenal Non-Textual Representations

Text-based CSCL environments have been shown effective as discussed above, especially when attention is paid to the formation of a learning community. Representing complex subjects involved in inquiry in such environments, however, requires moving beyond text alone. Effective science teaching uses multiple linked representations of ideas (NRC, 1996; Songer, 1998). Symbolic, physical, and graphical representations are used to teach science in face to face classes. These representations include simulations, models, equations, and algorithms. Teaching through inquiry requires both diverse representations of science and diverse methods of teaching (Lampert & Ball, 1999, Feiman-Nemser & Buchman, 1986).

Several strategies can be employed to facilitate this process of connecting students with representations of content (Wallace, Floden, & Putnam, in prep). First, activity structures can be created to engage students with representational tools. Such structures lead students through exploration and use of software and other representations, providing scaffolded use of the tools along with assignments that produce artifacts for class discussion. Second, multimedia artifacts, representations, and tools can be structured for viewing off line to accommodate bandwidth constraints. Third, collaborative tools, such as online persistent whiteboards or an electronic bulletin board that includes images linked to the text, can be used to illustrate and preserve complex representations. Each of these techniques requires strategies for using tools and representations that are not part of the discussion forum per se. These strategies include designing activity structures and discussion structures that engage students with important features of the representation and provoke discussion of those features.

For example, students might first use a complex representation of the data, such as a thermodynamics simulation, through a highly constrained assignment to explore and evaluate as part of a "jigsaw" (Aronson, Blaney, Stephan, & Silkes, 1978) assignment. Then each student would be asked to explain his or her portion of the jigsaw to others within a small online discussion group. Discussion and analysis within the online forum is thus facilitated by the group's common experience with the underlying artifact. Examples like the one briefly described here have two important features: (1) they give students a common experience with a particular representation of science or inquiry and (2) they provide a constrained set of language with which to talk about their experience using the representation. These kinds of techniques and strategies for representing subject matter afford all students the chance to engage deeply with the content and to discuss their ideas and understandings.

Ensure and Assess Comprehensibility of Materials

Finally, ensuring content comprehensibility is also critical. Experts produce written texts while answering emails, giving explanations, commenting on material, and creating curriculum. Everyday experience provides evidence that curriculum developers, teachers, and other experts sometimes fail to communicate their domain knowledge. One possible reason for this failing is that it is difficult for them to produce comprehensible texts, that is to say things in a comprehensible way. This can be labeled the "production problem." Due to the fact that teachers' and curriculum developers' domain knowledge is structured differently than that of students, it is not possible for teachers and curriculum developers simply to replace a scientific term with a colloquial one. Rather, they need to produce "new" explanations that are appropriate for students. Additionally, composing a comprehensible text requires a concrete idea about what makes the text comprehensible for the students. This can be labeled the "adaptation problem."

Research on text comprehensibility (e.g., Groeben, 1982; Langer, Schulz von Thun, & Tausch, 1974) can inform the process of ensuring comprehensibility of materials in text-based CSCL environments. This research shows that the interaction between characteristics of the reader (e.g., his previous knowledge and motivation) and features of the text (its readability) produces the comprehensibility of a text. When experts write texts to explain a certain topic to laypersons they must consider the text-characteristics, the knowledge of the layperson, and the interaction between both variables. Text comprehensibility can be divided into four dimensions: (1) simplicity, (2) structure-organization, (3) brevity-shortness, and (4) interest-liveliness (Langer, Schulz von Thun & Tausch, 1974, 1993.) These dimensions can be used to assess comprehensibility in text-based CSCL as well.

Another part of the solution involves considering the differences between experts and novices in their understandings of the subject matter. This research on expertise has a long tradition (Chi, Feltovich & Glaser, 1981; Ericcson, 1996; Sternberg & Horvath; 1999). For example, Berg & Brouwer (1991) analyzed teachers' assumptions about students' knowledge of the concept of motion and compared them with students' knowledge. Integrating this understanding of expert/novice differences is important to ensuring comprehensibility.

Finally, communication theory (H. Clark, 1996; H. Clark & Murphy, 1982) assumes that effective communication essentially relies on the ability to take the perspective of the other. Inferring what another person knows and adapting one's messages to the interlocutor's knowledge is necessary for successful mutual understanding (see Jucks, Paechter & Tatar, in this issue for more details). The differences in knowledge between teachers and students can intensify the ordinary problems in communication. Teachers and curriculum developers communicating with students can overcome systematic differences in knowledge by being aware of the perspective of their audience.

Therefore, to support learning and web-based knowledge communication it is important to identify discrepancies between anticipated and actual lay-perspectives. Isaacs and Clark's studies (1987) show that experts may easily adapt to laypersons' perspectives. In text-based CSCL, however, it may be more difficult to receive immediate feedback of students' understanding unless such capabilities are built explicitly into the tool and curriculum itself. Therefore, possibilities for feedback and analysis need to be facilitated effectively in text-based CSCL environment and curriculum. Content creators can assess text comprehension using a questionnaire (Appendix 1), which can be used as a tool for diagnosing discrepancies (Jucks, 2001). In situations where in-depth feedback is not feasible, the questionnaire can also be used without assessment of the actual lay-perspective. Working on the questionnaire can, in itself, lead to greater consideration of aspects of comprehensibility when writing texts and producing content for text-based CSCL environments.

Discussion: Text-based CSCL and Classroom Challenges to Inquiry

In this paper we have proposed a set of process-oriented strategies and approaches for scaffolding students in effective collaborative inquiry learning through text-based CSCL environments. We initially outlined four primary challenges to teachers in implementing inquiry in the classroom (as adapted from Krajcik et al., 1994). We now discuss how text-based CSCL environments can successfully address these classroom challenges to inquiry learning. In this discussion the text-based CSCL environments to which we refer are assumed to incorporate our proposed strategies and design approaches.

How Can Text-Based CSCL Environments Help Build Instruction around Authentic Problems That Are Contextualized, Important, Complex, Meaningful, and Interesting?

Teachers often find it challenging to organize instruction through driving inquiry questions that link concepts and diverse activities. Other challenges involve helping students to view the tasks as authentic while encouraging students to take ownership of the inquiry process and products. Text-based CSCL environments can overcome these challenges by orchestrating the activity structure for the teacher around the driving questions and thereby removing some of the cognitive and organizational load from the teacher. The environment can be designed to formulate problem cases concerning typical student situations, to provide representations clarifying naive and theoretical concepts, to suggest the application of theoretical concepts, to ask students to apply knowledge, introduce questions into the discourse, and to scaffold students' scientific argumentation.

In addition to organizing the activity through scripts and prompts, text-based CSCL environments can facilitate student ownership of the inquiry process and ideas. Activity structures that contrast students' own ideas allow students to scaffold one another to make sense of challenging science concepts and ideas. This added social and personal relevance contributes to students' ownership of the inquiry process.

In terms of authenticity, explanatory mechanisms in science change over time to accommodate new evidence as scientists work with one another, often through the forum of scholarly texts and meetings. Ultimately, patterns of logical and hypothetico-deductive reasoning connect these components through scientific argumentation. With text-based CSCL, students can engage with one another through the textual medium and artifacts of scientific discourse. Text-based CSCL can provide this opportunity in an authentic inquiry context wherein the students are sharing their own ideas with one another and getting relevant feedback as they collaboratively refine their knowledge base.

How Can Text-Based CSCL Environments Help Scaffold Student Understanding through Active Construction, Multiple Representations, Application of Information, Situated Contexts, and Strategic Thinking?

Teachers find it challenging to support students in designing, carrying out, analyzing, and interpreting investigations as well as sharing, critiquing, and revising their explanations. Text-based CSCL can be structured to focus students on critical elaborations of the learning tasks through prompt-based scripts. These structures for support may ease sub-tasks that are either irrelevant to learning or momentarily too difficult for the students. The prompt-based scripts can also challenge the learners to facilitate critical reflections and engage students in tasks such that interest is aroused to explore the domain in a self-guided manner on- or off-line. Similarly, the nature of the content material and the goals for the discussion can drive the organization of the content. All participants can have access through the environment to build sufficient background knowledge prior to discussion so that they can contribute as legitimate participants in the inquiry process.

An important consideration in these structures involves the nature of the learners. Graduate students will thrive under different levels and types of supports than eighth grade students. Native language speakers will thrive under different supports than second language learners. Relatively novice participants in text-based CSCL environments will need different supports than experienced users. Therefore in all cases, careful attention needs to be paid to the nature of the learners and their understanding of the material, the language, and the text-based CSCL environment. Once these considerations have been addressed, the environment can be structured to guide questions and structure interactions as students apply and refine their knowledge. Once the structure has been created, a moderator can further support students in building connections between their own ideas and the ideas expressed by other members of the community. The "sharpen the focus" and "deepen the dialogue" moderating strategies can support students in better articulating their ideas, designs, and arguments, which in turn support students in building better understanding.

How Can Text-Based CSCL Environments Help Create a Community of Learners Including Collaboration, Social Context, Negotiated Meaning, and Distributed Expertise?

Teachers often find it challenging to create communities in which students are willing to share opinions and ideas so that other students will listen, share, and take risks as they collaboratively explore ideas. Communities of learners are supported in collaborative negotiation of meaning when students are required to clarify statements while considering the relevance of other students' opinions. Inquiry is challenging for students because they have trouble supporting their ideas with evidence and because they do not have shared criteria for evaluating or giving explanations. Clarification often involves contrasting perspectives and also involves developing a repertoire of models. Well-designed text-based CSCL environments built around inquiry can scaffold inquiry by creating relationships that elicit students' conceptual resources to refine the group's ideas. A moderator enhances this process by honoring multiple perspectives to create a community of learners that encourages participants to consider other viewpoints, methodologies, and perspectives.

An electronic community of learners requires a common base of experience in addition to its collaborative structures. Text-based CSCL environments can provide multiple representations and artifacts to provide that common base while allowing enough freedom of interaction with the diverse representation and data sources for the participants to conduct real inquiry. Ensuring the comprehensibility of these materials ensures that this common base allows all students access.

How Can Text-Based CSCL Environments Help Integrate Cognitive Technological Tools into the Curriculum To Support Inquiry?

Finally, although using a CSCL environment by definition incorporates technology, learning technologies can do much more than deliver content. Learning technologies can provide critical tools to support students' cognition (Jonassen, 1995). Cognitive technologies can augment students' cognition by providing alternative mechanisms for information gathering (perception and selection), processing (computational power and alternative models of information flow and organization), and output (representation, communication, and impact on the environment). These technologies thus reduce the cognitive load on students as students represent and process models and concepts (Scaife & Rogers, 1996). Cognitive technologies, therefore, scaffold students in tasks they could not master without the mediation of the tools (LaJoie, 2000; Pea, 1987). Furthermore, scientists use these same types of cognitive tools to process and analyze data. By incorporating these tools into the curriculum through text-based CSCL environments we not only support inquiry learning but also make that inquiry experience more authentic.

Many teachers, however, need support incorporating cognitive technological tools into the inquiry process as well as helping students to use those tools. This support for teachers and students should be at the crux of the design of a text-based CSCL environment because it addresses the "practicality ethic" issues that impede the successful introduction of new methodologies into the classroom (Cuban, 1986, 1993). In order to facilitate a transition from traditional classroom activities toward inquiry, we must provide the supports for the teacher and the students to access these tools. Incorporating the tools into the structure of the environment and including prompt-based scripting to support initial use of the tools can both lower the initial teacher requirements for importing these tools into the classroom and provide integrated scaffolding in the use of the tools for students.

Final Thoughts: Synergies

Text-based CSCL environments can be designed to accommodate everyday classroom challenges to collaborative inquiry learning. Our proposed strategies and design considerations provide benchmarks for curriculum designers and educators designing or choosing text-based environments to support inquiry learning.

In making these choices, educators should consider the strategies and supports in their relationship with one another as well as independently. All of these strategies reinforce one another and significant synergies are afforded through their effective combination. Contrasting students' ideas is more successful when the instructions and text are comprehensible, the students are scaffolded in critiquing one another's ideas through scripts, and a moderator is available to keep students from settling on non-productive vectors. Rich non-textual representations help make the textual content more comprehensible, as do prompted-scripts and moderators. A teacher-moderator will be able to accomplish more in a rich discussion involving these multiple levels of support because greater student participation and idea elicitation provide fertile terrain in which to guide more productive discussions. By further exploring and refining the underlying principles connecting these different levels of support we can continue to create even more effective text-based CSCL environments to scaffold inquiry learning by all students.

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Appendix. Questionnaire assessing laypersons' perspective on text comprehensibility (Jucks, 2001)

Please give your opinion about the text by marking the corresponding boxes.

scale simplicity						
To a layperson, this text is vivid.	☐	☐	☐	☐	☐	To a layperson, this text is not vivid.
To a layperson, this text contains familiar words.	☐	☐	☐	☐	☐	To a layperson, this text contains unfamiliar words
To a layperson, this text is concrete.	☐	☐	☐	☐	☐	To a layperson, this text is abstract.
To a layperson, this text contains short, simple sentences.	☐	☐	☐	☐	☐	To a layperson, this text contains long, complicated sentences.
To a layperson, technical terms are being explained in this text.	☐	☐	☐	☐	☐	To a layperson, technical terms are not explained in this text.
To a layperson, this text contains a simple description	☐	☐	☐	☐	☐	To a layperson, this text contains a complicated description
scale organization						
To a layperson, this text is organized.	☐	☐	☐	☐	☐	To a layperson, this text is unorganized.
To a layperson, this text is clear.	☐	☐	☐	☐	☐	To a layperson, this text is unclear.
To a layperson, everything in this text is in order.	☐	☐	☐	☐	☐	To a layperson, this text is chaotically organized.
To a layperson, this text contains a good differentiation between essential and rather unimportant issues.	☐	☐	☐	☐	☐	To a layperson, this text contains a bad differentiation between essential and rather unimportant issues.
To a layperson, the main idea of this text is obvious.	☐	☐	☐	☐	☐	To a layperson, the main idea of this text is not obvious.
To a layperson, this text is logically structured.	☐	☐	☐	☐	☐	To a layperson, this text is structured incoherently, confusingly.
scale brevity-shortness						
To a layperson, this text is centered around its general message.	☐	☐	☐	☐	☐	To a layperson, this text deviates from its general message.