Chapter 11
Technology-Enhanced Learning Environments to Support Students' Argumentation

Douglas B. Clark, Karsten Stegmann, Armin Weinberger, Muhsin Menekse, and Gijsbert Erkens

Technology-enhanced learning environments offer a range of features to facilitate active learning through evidence-based argumentation (e.g., Fabos & Young, 1999; Kollar et al., 2005; Marttunen & Laurinen, 2001; Pea, 1994; Roschelle & Pea, 1999; Schellens & Valcke, 2006). This chapter examines the affordances of these environments, the research behind their development, and the expected benefit of technology-enhanced argumentation. We discuss environments specifically developed for science education as well as other environments that have strong relevance for argumentation in science education. We organize our discussion around two main categories of support for argumentation: facilitating collaborative argumentation and facilitating the construction of individual arguments and contributions. After discussing representative features for supporting argumentation within online environments, we discuss the integration of subsets of these features within four environments in alignment with the specific pedagogical goals and theoretical commitments of their developers. Finally, we discuss future directions for research on argumentation and learning in technology-enhanced environments.

Facilitating Collaborative Argumentation

We first focus our discussion on features and structures designed to support collaboration and interaction in technology-enhanced environments. In this section, we discuss potential affordances in terms of (a) modes of communication, (b) group composition, (c) co-creation and sharing of artifacts, and (d) awareness tools.

Modes of Communication

Online learning environments incorporate both asynchronous and synchronous collaborative communication interfaces that can potentially promote and support interactions between students.

S. Erduran and M. P. Jiménez-Aleixandre (eds.), *Argumentation in Science Education.*

Asynchronous Modes. Many online learning environments incorporate opportunities for asynchronous online collaboration and discussion. Temporal persistence and asynchronism may foster engagement in high-quality argumentative processes (e.g., de Vries et al., 2002; Pea, 1994). Asynchronous communication facilitates task-oriented discussions and individual knowledge construction by allowing participants time to reflect, understand, and craft their contributions and responses (Kuhn & Goh, 2005; Marttunen, 1992; Schellens & Valcke, 2006). This expanded time allows students to construct and evaluate textual arguments more carefully than in face-to-face environments (Joiner & Jones, 2003; Marttunen & Laurinen, 2001). The text-based nature of these asynchronous online environments (as opposed to speech-based) can supplement the construction of complex and well-conceived arguments (e.g., de Vries et al., 2002). Recent computer-mediated communication techniques, such as blogs and wikis, also allow the construction of non-sequential arguments in hypertext (Carter, 2003; Wolfe, 1995). Asynchronous modes may also potentially provide more equitable access and participation for students engaging in argumentation than face-to-face settings because of simultaneous access and participation opportunities (Hsi & Hoadley, 1997). Asynchronous modes that allow anonymous contributions may increase this equitable access and participation (Hsi & Hoadley, 1997).

Synchronous Modes. Other online learning environments, such as *CONNECT* and *TC3 (Text Composer, Computer-supported & Collaborative)*, offer text-based synchronous chat facilities to support the collaborative process. Task-oriented synchronous chat affords simultaneous deliberation and coordination as students work together on a shared artifact, such as a co-constructed text (de Vries et al., 2002; Janssen et al., 2006). Current research suggests that providing ways for students to coordinate resources and negotiate how to proceed with a task in this manner can foster productive collaborative learning (Barron, 2003; Pfister, 2005; Rogoff, 1998). Besides facilitation of coordination and negotiation, synchronous chat may also allow immediate feedback on argumentation and thus facilitate co-construction of argumentation sequences. Munneke et al. (2007) found in a comparative study between synchronous and asynchronous modes that students in the synchronous chat condition argued in a more elaborated and deep way than students using the asynchronous forum on the same argumentative writing task. However, in contrast to their hypothesis, students using the asynchronous forum produced more accurate argumentative texts.

In summary, asynchronous and synchronous modes offer different affordances. Asynchronous modes of communication allow learners to participate more equitably and to spend more time on constructing well-conceived and elaborate arguments, whereas synchronous modes of communication can deliver a higher degree of joint elaboration and construction of arguments but place higher demands on learners' ability to interpret challenging conceptual material.

Group Composition

Strategic composition of groups can maximize the likelihood of successful interactions. Organization of heterogeneous groups based on a variety of learner characteristics (e.g., prior knowledge, gender, opinions) can expose learners to a broad bandwidth of perspectives and resources. Technology can distribute these resources, analyze student characteristics, and compose groups of students accordingly.

Clark and Sampson (2005, 2007, in press), for example, developed the *Personally Seeded Discussion Interface* to organize students with different perspectives on a topic into asynchronous discussion forums using the students' ideas as the initial seed comments. This example is discussed in greater detail later in this chapter. Similarly, Jermann and Dillenbourg (2003) designed the *ArgueGraph* script, which identifies students' opinions through a questionnaire and then represents the students' positions on a graph. The software then matches pairs of opposing opinions with the largest distance on the graph into groups to construct and exchange arguments and counterarguments. Throughout this process, the software dynamically represents changes in the participants' positions on the graph. Jermann and Dillenbourg (2003) showed that groups composed in this manner demonstrated an increased engagement in the processes of argumentation and learning.

Likewise, environments can also distribute and redistribute roles and activities to individual group members to facilitate collaborative argumentation independent of learners' actual perspectives. In a problem-oriented online learning environment, for example, the assignment and rotation of the roles of "case analyst" and "constructive critic" with prompts to support typical activities of those roles has been shown to facilitate knowledge acquisition (Weinberger et al., 2005).

Co-Creation and Sharing of Artifacts

Some online learning environments encourage collaboration through the co-creation and sharing of intellectual artifacts that present or visualize arguments (e.g., Kirschner et al., 2003). Students in these environments therefore create, modify, and share permanent external representations of their ideas and arguments with one another. Producing these external representations engages students in proposing, supporting, evaluating, and refining their ideas. Furthermore, external representations can help learners identify faulty or incomplete lines of argumentation and elicit task-relevant knowledge (Fischer et al., 2002). This type of collaboration extends beyond simply sharing or combining ideas; it requires students to engage in a process of dialogic argumentation. For example, the *CONNECT* environment (*Confrontation, Negotiation, and Construction of Text*) enables students to co-create a text through interfaces that structure the nature of the task and promote communication between the students (de Vries et al., 2002). Similarly, the *TC3* environment provides separate source materials for the individual group members, chat functionality, a shared argumentation map, and a shared text construction space (Erkens et al., 2003). Another example of a tool designed to foster dialogic argumentation through the co-construction of an intellectual artifact is the *DUNES* system (Schwarz & Glassner, in press). This tool encourages students to engage in dialogic argumentation as they co-construct a rich argumentation map in which shapes represent types of contributions (e.g., information, argument, comment, or question) and arrows between shapes show connections (with solid arrows signifying support and dashed arrows signifying opposition).

In summary, the co-creation and sharing of artifacts can facilitate argumentation by guiding learners' attention toward argumentation gaps and elicit task-relevant knowledge (Fischer et al., 2002; Suthers & Hundhausen, 2001). This approach includes tools that enable collaborative writing as well as tools that support the collaborative creation of argumentation maps.

Awareness Tools

Environments can incorporate tools to increase group members' awareness of the nature and quality of contributions and participation within the group. These tools can increase students' awareness, for example, of the number of words students contribute, the number of comments made, or the connections established in terms of who has spoken to whom (e.g., Erkens & Janssen, 2006; Dillenbourg, 2002). Increased awareness of information may facilitate productive dialogic argumentation because students understand how various individuals are participating in a discussion (Jermann et al., 2001) and participants can modify the ways they engage in argumentation (Hesse, 2007). The sections later in this chapter about the *VCRI* and *CASSIS* environments provide additional discussion and specific examples of these awareness tools. In summary, awareness tools represent a new approach to facilitating collaborative argumentation. These tools support the self-regulating capacities of collaborative learners. Students are made aware of possible strengths and deficits regarding the group's collaborative activities and of possible gaps in the group's argumentation. Based on this feedback, students can self-correct their collaborative argumentation accordingly. The quality of the feedback provided obviously represents a critical variable in effectiveness of this approach.

Facilitating the Construction of Individual Arguments and Contributions

In addition to scaffolding students' collaboration in argumentation, technology can also provide specific supports for students as they craft their arguments and contributions. Researchers have developed a wide range of features to support students in these processes. We structure our discussion of these features in terms of access to data, evaluation of data, and argument construction.

Access to Data

Science education places strong emphasis on “data.” Many phenomena, however, prove inaccessible, inappropriate, or impractical for investigation in a traditional classroom context. Technology-enhanced learning environments can provide access to data to facilitate students’ investigations and thus argumentation. One approach involves embedding resources in knowledge bases without predefined access order or sequence. These knowledge bases can be generated by the students themselves as in *CSILE* (Scardamalia & Bereiter, 1994) or by curriculum developers or teachers as in *WISE* (Linn et al., 2003). These knowledge bases may range from glossaries or reports of experiments to recordings of experiments or simulations. With the help of index pages or search engines, students can search and use these resources to support their claims or critique the arguments of others.

Kolodner et al. (1997), for example, built an indexed case library that students search for examples and facts as evidence for their arguments about specific issues. To support students’ examination of counterarguments to their own line of argumentation, the case library provides and indexes alternative solutions. Kolodner et al. (1997) showed that the case library supported students’ construction of counterarguments and refined learners’ understanding of what makes a good argument. Students with high prior argumentative skills derived the most benefit from this environment.

Enriched representations can also provide significant interrelated information to students (Fisher & Larkin, 1986). Online learning environments can, for example, incorporate media-rich representations of the learning task, materials that enhance the authenticity of the learning task, and contextual anchors to facilitate student learning (Bransford et al., 2000; Cognition and Technology Group at Vanderbilt, 1997). These environments can challenge students to identify the relevant problem information within complex problem cases and then create an appropriate solution strategy using these materials. Students can also collect evidence for their argumentation by observing rich representations. Visualizations and simulations may allow students to explore aspects of the subject matter to support a specific claim, thereby potentially increasing the persuasiveness of their arguments (Oestermeier & Hesse, 2000).

In summary, technology environments can increase students’ access to rich data in support of their argumentation. This access may involve structured knowledge bases, unstructured knowledge bases, media-rich representations, visualizations, and other formats. In all cases, students require activity structures with sufficient scaffolding to support successful interactions resulting in the integration of this data into their arguments.

Evaluation of Data

Environments can provide specific functionality to help students analyze the data in terms of its meaning and its relevance to their arguments. Early work of this type was conducted with the SenseMaker tool within the *KIE* and *WISE* environments (Bell, 1997, 2004; Bell & Linn, 2000). This work showed that students' understanding of the core issues, evidence, and arguments benefited from working with a tool that helped them analyze the conflicting pieces of evidence at the core of a debate. The *VCRI* environment discussed in the second half of this chapter provides another example of these diagramming functionalities.

Related to this work, the *BGuILE* environment helps students design and practice scientific inquiry through investigation, refine their own explanations and reasoning, and critique other students' explanations (Reiser et al., 2001). The *BGuILE* environment integrates dynamic visualizations and outlining environments to help students learn, understand, and integrate new and complex knowledge and concepts that students might not otherwise address (Reiser, 2002). These supports for conducting scientific analysis of data in support of argumentation are also discussed in greater detail in the second half of this chapter.

In summary, students benefit not only from access to data but also from access to scaffolding in the evaluation of that data. Technology-enhanced environments can support students in creating sound arguments through this analytical scaffolding.

Argument Construction

Technology can also directly support students' construction of arguments and dialogic contributions. These approaches can help students build thoughtful well-constructed arguments in rhetorical as well as dialogic contexts. One approach focuses on structural elements. For example, *Belvedere* supports students' construction of sound arguments through a Toulmin-inspired graphical template of the structural components of an argument (Suthers & Hundhausen, 2003). While support of the evaluation of data is a key feature of tools like *Belvedere*, these tools can also facilitate the construction of sound arguments by visualizing respective claims, relevant evidences, and possible qualifications (Fischer et al., 2002; Kirschner et al., 2003; Suthers & Hundhausen, 2001).

A similar approach builds on a scripted cooperation perspective. Developers create *scripts* to guide students through argumentative processes. These scripts can specify, sequence, and assign roles and activities for students (Fischer et al., 2007; Weinberger, 2003). For example, the script of Kollar et al. (in press) supports collaboration by prompting learners to provide arguments that consist of claims, data, and warrants. This scripted cooperation approach is also used to structure dialogic exchange following the idea of dialectics (Hegel, 1965) and argumentative knowledge construction (Leitão, 2000).

A further example of scripting the construction of individual comments is the work of Clark and Sampson (2005, 2007, in press) discussed later in this chapter. Clark and Sampson provide a series of pull-down menus from which students choose a combination of sentence fragments to craft their opening claim within the argument to ensure that students' conceptions of a phenomenon focus on the salient issues and involve sufficient elaboration so that other students notice differences and want to discuss them.

In summary, technology-enhanced environments can directly support students' construction of arguments and individual contributions within larger dialogic contexts. These supports can focus on specific structural elements, core content ideas, or even the role of a contribution within the larger framework of the argument.

Environmental Integration of Multiple Features

While we have discussed environmental affordances in terms of individual categories, most technology-enhanced environments integrate multiple features to support argumentation. Designers therefore have flexible and broad palettes of features with which to create complex integrated activity structures. The resulting environments can be thought of as cognitive tools that shape *how* people think about accomplishing a task because they have a strong influence on the *ways* people attempt to accomplish a task (Hutchins, 1995; Norman, 1990, 1993). This is particularly true when tasks require individuals to gather, organize, communicate, or make sense of information (Reiser, 2002). According to Norman, when cognitive tools are used to represent and manipulate information, these tools become vehicles through which people interact with the subject matter. Thus, the nature of the task emerges through the interactions of people, subject matter, and tools. In this section we examine how four environments, *TELS: Probing Your Surroundings*, *BGuILE*, *CASSIS*, and *VCRI*, have integrated different subsets of features based on the designers' theoretical commitments and pedagogical goals.

TELS: Probing Your Surroundings

The *TELS: Probing Your Surroundings* project (Clark, 2004) focuses on helping students investigate the scientific concepts of thermal equilibrium and conductivity. *Probing* was developed within the *Technology Enhanced Learning for Science (TELS)* online environment and integrates standard features from *TELS* with custom software to support students' data collection, explanation creation, and argumentation. The goal of *Probing* involves helping students understand challenging science concepts by supporting their reconciliation of these concepts with their everyday experiences.

Design principles and goals. The structure of *Probing* focuses on a sequence of four stages. The *Predict* and *Observe* phases of the design focus on facilitating students' investigation of the data that will be discussed. The *Explain* phase focuses on helping students construct explanations (referred to in the project as "principles") to describe patterns in the data that they have collected or found in light of other evidence from their classroom and homes. The *Critique* phase focuses on creating groups of students who have produced different principles to describe the data and facilitating online discourse among the students where they critique each other's principles in light of the evidence and work toward consensus through scientific argumentation. The overarching goals of the design thus focus on students' understanding of the scientific concepts as well as the nature of scientific argumentation.

Integration of features to instantiate design principles and goals. Students work in pairs with one computer for each pair. They begin the *Predict* phase by making predictions about the temperature of everyday objects around them in the classroom. Students record this information in data tables and notes that they can access at any time during the project. The goal of this phase involves engaging the students in active reflection upon their prior ideas and experiences to provide a foundation to guide students' subsequent investigations as well as to facilitate their re-examination and revision of these initial ideas during the project.

In the *Observe* phase, students use thermal probes and computer simulations to investigate the temperatures of the objects from the *Predict* phase. This *Observe* phase attempts to help students recognize possible conflicts between their predicted ideas and the actual phenomena. From an argumentation perspective, the goal of the *Observe* phase focuses on providing students with access to rich data and evidence with which to engage in argumentation about the phenomena under investigation.

In the *Explain* phase, students create explanations (which the project calls "principles") to describe patterns they have discovered in the data. Students use a web-based interface to construct their principle from a set of predefined phrases and elements using a pull-down menu format (Fig. 11.1). The predefined phrases include common ideas and misconceptions that students use to describe heat flow and thermal equilibrium. These phrases were identified through the misconceptions and conceptual change literature (e.g., Clough & Driver, 1985; Erickson & Tiberghien, 1985; Harrison et al., 1999) and a thermodynamics curriculum development project (Clark, 2006; Lewis, 1996; Linn & Hsi, 2000). This principle creation process serves multiple purposes. Students often have difficulty generating a detailed explanation of a phenomenon (deVries et al., 2002). Students also have difficulty focusing on the aspects of a phenomenon that experts would consider relevant (Chi et al., 1981, 1982). The pull-down format addresses both of these issues by ensuring that the students' explanations of a phenomenon focus on the salient issues and are sufficiently elaborated so that other students notice differences and want to discuss them. The pull-down menu format also provides data to the software for assigning students to discussion groups with other students who have constructed different explanations.

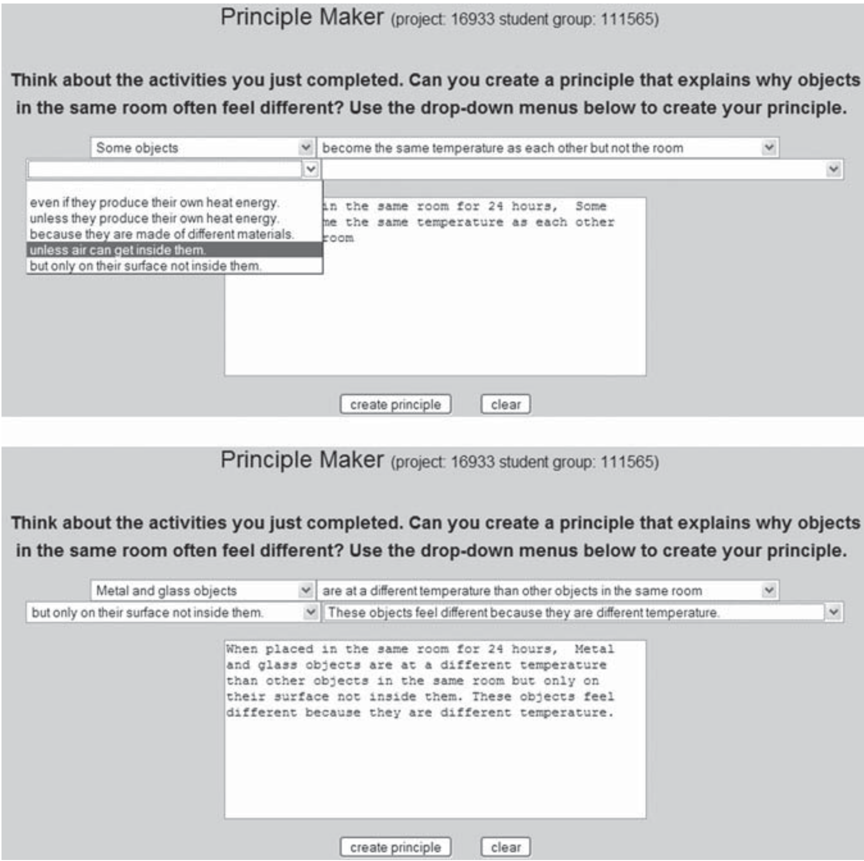

Fig. 11.1 TELS Principle Maker interface

Finally, during the *Critique* phase of the design, students debate and evaluate the validity of each group's principle. Each pair of students has their principle placed into an asynchronous discussion forum as an initial seed comment. The decision to use student-generated principles as the seed comments was based on research that suggests that the social relevance of an activity, and student interest in it, can be increased by having students discuss their own ideas and the ideas of their classmates (Hoadley, 1999; Hoadley & Linn, 2000). The discussions develop around the different perspectives represented in the seed comments, ideally through a process of comparison, clarification, and justification.

Research in Probing. Current research using the *Probing* environment investigates issues surrounding optimal group organization, initial discussion parameters, and students' incorporation of evidence into their argumentation. In terms of group creation, the research focuses on the contribution of the group creation process to subsequent argumentation. In terms of initial discussion parameters, the research focuses on the impact of incorporating students' own principles as the starting comments for the discussions rather than a balanced set of generic prompts carefully chosen to represent a range of the key ideas and misconceptions that students typically express. In terms of students' incorporation of evidence into their argumentation, the research focuses on the degree and manner in which students incorporate evidence from the experiments and simulations into their argumentation.

BGuILE: Biology-Guided Inquiry Learning Environments

The *BGuILE* environment helps middle school and high school students design and practice scientific inquiry through investigation, create, and refine their own explanations and reasoning, and critique other students' explanations (Reiser et al., 2001; Tabak et al., 1999). Students work collaboratively to explain scientific phenomena such as how natural selection changes a species, how antibiotics affect bacteria, or how endangered animal species like the Florida Panther can be saved. All of these projects involve computer-based scenarios and classroom activities in which students conduct real scientific investigations (Tabak et al., 1999).

Design principles and goals. The design of *BGuILE* focuses on building connections between domain-general supports for scientific reasoning and domain-specific supports for rational and critical approaches related to scientific inquiry. The goal involves encouraging students to develop questions, construct explanations, and engage in scientific investigation and argumentation in a domain-specific manner. In other words, not only does the design of *BGuILE* explicitly represent domain-general scientific-reasoning strategies within the structure of the activities and software, the design of *BGuILE* also strives to help students understand domain-specific versions of these strategies. This domain-specific support is based on an analysis of scientific work in the target domain and the articulation of an investigation model that reflects key questions, principles, relationships, and work processes in the target domain. Domain-specific scaffolds are then designed to reflect this investigation model. For example, when *BGuILE* prompts students to make comparisons in *The Galapagos Finches* (Fig. 11.2), *BGuILE* simultaneously helps students understand the types of comparisons that a biologist would make.

More specifically, *BGuILE* focuses on four primary strategic design principles: explanation-driven inquiry, explicit representations of theories and strategies, integration of classroom and technology supported learning activities, and ongoing reflection (Reiser et al., 2001). *BGuILE* organizes instruction around "strategic tools" and "strategic artifacts." Strategic tools are tools that "students use to access, analyze, and manipulate data to make the implicit strategies of the discipline visible to students" (Reiser et al., p. 276). Strategic artifacts are defined as "the work products that students create to represent the important conceptual properties of explanations and models in the discipline" (p. 276).

Integration of features to instantiate design principles and goals. Explanation-driven inquiry is the first strategic design principle of *BGuILE*. The motivation of this principle involves scaffolding students' construction of explanations that state

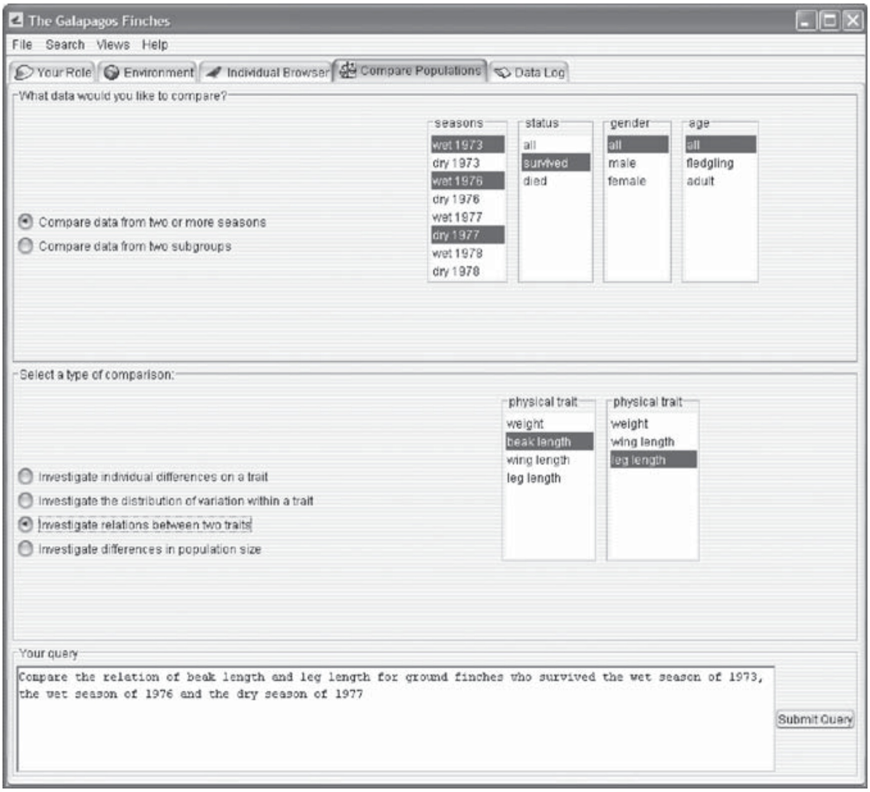

Fig. 11.2 Comparing populations in the BGuILE *Galapagos Finches* project

rational, causal mechanisms and justify the gathered data. Sandoval & Reiser (2004) explain this idea as:

> Explanation-driven inquiry entails a shift both in the nature of students' work in the classroom and their underlying view of that work. Accomplishing this shift requires tools that shape the ways that students construct the products of their work, curricular activities that emphasize the valued criteria of these products, and teaching practices that support students' understanding of these criteria and help to connect their inquiry experiences to core disciplinary theories. (p. 4)

As an example, in *The Galapagos Finches*, students learn about natural selection by exploring variations in the populations of plants and animals on the Galapagos Islands. Students collect data about the animals and conditions as part of this exploration. Data might include, for example, population levels, beak sizes, plant diversity, and weather conditions from different seasons across several years. According to the explanation-driven inquiry principle, students' explanations should develop causal relationships explaining the data in relation to natural selection. The teacher and the software help students in the process of determining what constitutes acceptable explanations and powerful evidence in scientific argumentation across these activities (Tabak & Reiser, 1997; Tabak, 1999; Reiser et al., 2001; Sandoval & Reiser, 2004).

Explicit representation of theories and strategies. The software tools that students use and the types of artifacts they construct should explicitly represent and model appropriate strategies and theoretical frameworks (Reiser et al., 2001). The domain-specific supports are incorporated in all phases of the inquiry—analysis as well as synthesis. The domain-specific supports therefore exist in the questions-based interface for data collection and analysis, in the data log for data analysis and organization/synthesis, and in the explanation constructor for synthesis and explanation articulation. Students, for example, construct their explanations, organize their investigations, and insert evidence using *ExplanationConstructor*, which is an electronic journal embedded in the learning environments (Sandoval & Reiser, 2004). This software is similar to *SenseMaker* (Bell & Linn, 2000) or *CSILE* (Scardamalia & Bereiter, 1994). The major difference between *ExplanationConstructor* and the other collaborative argumentation environments is that it includes the fundamental pieces of the disciplinary structure in the *explanation guide*s (Reiser, 2002).

Integration of classroom and technology-supported learning activities. The first key criterion for this principle dictates that design should integrate existing learning activities that are already components of standard curriculum used in schools within the new activities and software. Basing activities on prior experiences of both students and teachers maintains the connection between existing practices and the new activities. For example, *BGuILE* takes two important but relatively discrete activities from a typical curriculum and then modifies and integrates them into one activity as part of a project based investigation (Reiser et al., 2001). The second major criterion for this principle dictates that activities should progress in an organized and gradual way to support students' successful engagement in scientific inquiry. This progression depends on the students' prior knowledge, grade levels, and the complexity of the subject. For example, high school biology curricula should incorporate more complicated graphical data than middle school curricula (Reiser et al. 2001).

Ongoing reflection. According to this principle, designers should have two goals. First, they should encourage students to frequently evaluate their own explanations, evidence, assumptions, and results. Second, designers should provide options for students to compare and critique others' findings and explanations. Students should then resolve possible differences among explanations through discussions. *ExplanationConstructor*, for example, helps students record and review their own work. Other *BGuILE* environments, like TB Lab or Florida Panther, have specific tools to assist students in managing their collected data and inferences. The *Data Log* (see Fig. 11.3), for example, allows students to record the date, time, category, and "nature of comparison" in notes related to their data (Reiser et al., 2001). *Data Log* thus helps students organize and classify their data throughout the investigation. These records in *Data Log* subsequently help students as they craft their explanations in the *ExplanationConstructor* journal. Finally, students use *ExplanationConstructor* to compare and evaluate each others' explanations and findings (Reiser et al., 2001). Throughout the scientific inquiry, students continuously have the opportunity to reevaluate their work and discuss each others' work in a collaborative manner.

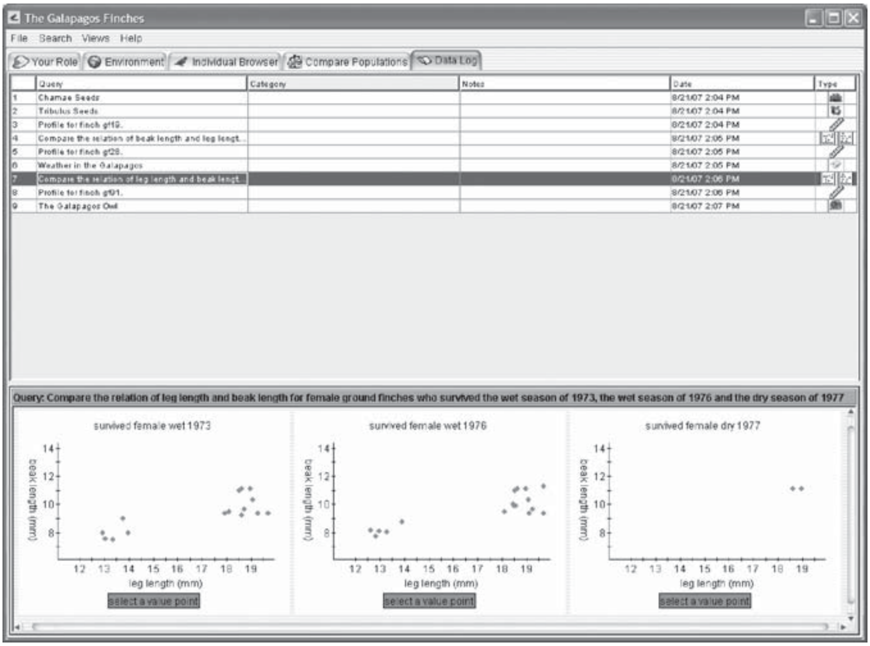

Fig. 11.3 BGuILE Data Log

Research in BGuILE. Research on students' classroom artifacts suggests that *BGuILE* successfully engages students in inquiry into detailed and complex problems (Reiser et al., 2001). "Most groups of students are able to arrive at reasonably well-justified explanations and models and can recount the evidence on which their explanations are based" (Reiser et al., 2001, p. 295). The integration of classroom and technology supported learning activities, or synergy of supports (Tabak, 2004), seems to be particularly productive in helping lower-achieving students reach inquiry performance that reflects the sophistication of higher-achieving students (Tabak, 2000). Particular teacher moves and the emphasis on evidence-based explanation-driven inquiry can also create more symmetry between teacher and student roles, which can have positive consequences for a sense of efficacy in science as well as content and skill achievement (Tabak & Baumgartner, 2004). *BGuILE* research also focuses on inferential validity in terms of the causal coherency of students' explanations (Sandoval, 2003; Sandoval & Millwood, 2005). According to these analyses, students' explanations are predominantly coherent even though they sometimes use illogical inferences to justify their positions. Finally, research on specific *BGuILE* software tools, such as the *ExplanationConstructor*, underscores the efficacy of these tools in supporting scientific inquiry through argumentation and helping students express their reasoning and beliefs in meaningful ways (Sandoval &Reiser, 2004).

CASSIS: Computer-Supported Argumentation Supported by Scripts

The *CASSIS* environment (Computer-supported Argumentation Supported by Scripts—experimental Implementation System) was developed as part of a research project on collaboration scripts by Weinberger et al. (2007). The scripts under investigation targeted several different collaborative learning processes, such as participation (Weinberger et al., 2001), epistemic activities (Weinberger et al., 2005), transactivity (Weinberger, 2003), and argumentation (Stegmann et al., 2004). The argumentative collaboration scripts combine two theoretical perspectives: supporting students' construction of sound arguments in alignment with Toulmin's model of argumentation (Toulmin, 1958) and structuring the dialogic exchange in alignment with the ideas of Leitão (Leitão, 2000).

Design principles and goals. CASSIS fosters argumentation through collaboration scripts (i.e., instructional plans) that specify and sequence collaborative learning activities. When needed, these scripts assign various activities to the individual learners (Kobbe et al., in press). Collaboration scripts typically focus on activities that researchers associate with deeper cognitive elaboration and therefore knowledge acquisition but learners seldom perform correctly (King, 2007). High-quality argumentation has been regarded as such an activity (e.g., Baker, 2003; Kuhn & Goh, 2005; Leitão, 2000). The quality of argumentation can be described by at least two dimensions: the crafting of sound arguments and the structuring of the dialogic exchange (Weinberger & Fischer, 2006). Focusing on the crafting of sound arguments puts more emphasis on individual components of a single argument (Toulmin, 1958), such as the explicit occurrence of reasons (van Eemeren, 2003; Voss et al., 1983). Focusing on the structuring of the dialogic exchange, the emphasis is on mutual reference during argumentation, such as arguments that counter the arguments of a learning partner (Jermann & Dillenbourg, 2003; Resnick et al., 1993).

Integration of features to instantiate design principles and goals. Within the environment, students collaboratively discuss short problem cases. The three students in each discussion group collaborate from different locations using a customized asynchronous text-based discussion board. The main interface includes three areas: instructions in the upper left corner, a visualization of the current case in the lower left corner, and the online discussion for the current case. The interface allows the students to exchange text messages that resemble emails. Learners can either start a new topic by posting a new message or reply to earlier messages. Each message consists of a subject line, author information, date, time, and the message body. The learning environment sets the author, date, and time automatically. The learners enter the subject line and the body of the message.

The script for the construction of single arguments organizes a student's argument within the comment creation interface of the discussion board (see Fig. 11.4). This script builds on a simplified Toulmin model (Toulmin, 1958) by providing input text boxes for a claim, grounds, and qualifications. Each text box of the interface is

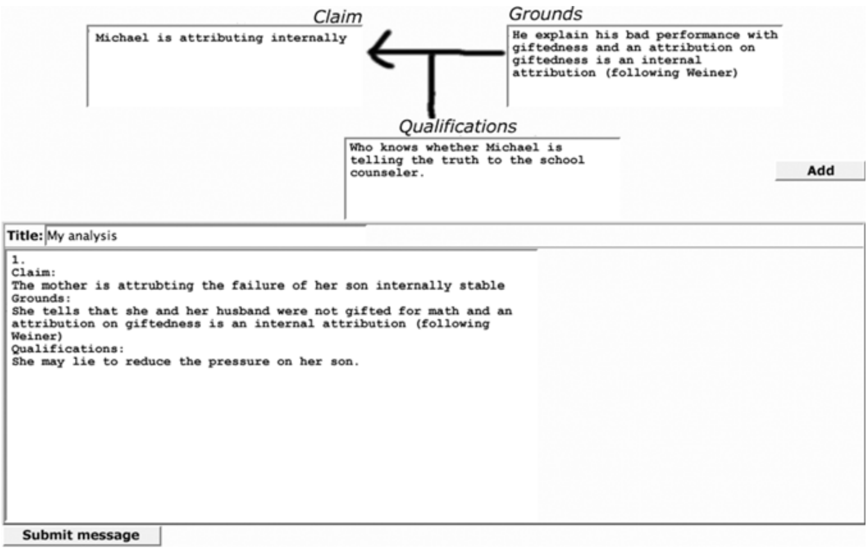

Fig. 11.4 Single argument script for CASSIS

completed by the learners. By clicking the command button ("Add") to submit the comment, the contents of the three input text boxes are combined into a prespecified textual structure of the argument. Learners are not limited to using the three input text boxes for constructing single arguments. Students can write questions, comments, or expressions of emotion directly into the main input text box.

The script for the construction of argumentation sequences guides students through Leitão's specific argument–counterargument–integration pattern by presetting the subject of each posted message automatically depending on its position in the progression of the discussion thread. The first message in a chain is labeled "Argumentation." The answer to an argument is automatically labeled as "Counter Argumentation." The reply to a counterargument is labeled as "Integration." The next message is again labeled "Counterargument," then "Integration," and so on. In this way, discussion follows the path of Leitão's model.

Research in CASSIS. The research conducted with *CASSIS* investigates how computer-supported collaboration scripts can facilitate argumentative knowledge construction in online discussions. Argumentative knowledge construction focuses on the construction of domain-specific and domain-general knowledge through collaborative argumentation. With the help of *CASSIS*, the mutual relations between individual cognitive processes, collaborative argumentation, and knowledge acquisition are examined. Therefore, argumentative knowledge construction is analyzed with respect to epistemic activities, the formal quality of argumentation, and social modes of co-construction including transactivity (i.e., learners' mutual reference in online discussions.) The research findings demonstrate that the investigated scripts do have the desired main effects. For instance, the script for the construction of single arguments actually helps learners to construct more sound single arguments and learners acquire knowledge about the construction of single arguments. Some scripts, however, have unwanted side effects. An epistemic script, for example, facilitated learners in solving the learning task but had detrimental effects on knowledge acquisition. Current projects aim to implement the automated analysis of natural discourse corpora (see Dönmez et al., 2005) in *CASSIS* to achieve real-time adaptivity of collaboration scripts. The analysis of the contributions of the individual learners will be used to fade scripts in or out.

VCRI: Virtual Collaborative Research Institute

The *VCRI* is the core environment of the *Computerized Representation of Coordination in Collaborative Learning (CRoCiCL)* project which concentrates on joint visualizations and collaborative learning by inquiry (Janssen et al., 2006). The *VCRI* was developed from the earlier mentioned *TC3* environment. The *VCRI* is a multiplatform groupware environment designed for students ranging from primary school to college level working collaboratively with specialized tools for specific tasks (Jaspers & Broeken, 2005). The *VCRI* has approximately twenty special software tools, such as *Chat, Participation, Debate, Planner, Cowriter, Forum, Diagrammer,* and *Shared Space* (Broeken, 2006). While much of the research in *VCRI* has not focused on science content, the features and design offer much to support scientific argumentation.

Design principles and goals. Although each group member appears to work individually, the *What You See Is What I See* (WYSIWIS*)* design principle of the *VCRI* allows students to share all tools except their personal notes. All members work on one task and/or a product synchronously or asynchronously. According to this design principle, using the same interface provides very efficient and effective collaboration across group members. During the collaborative inquiry, each group member can edit the content of the tool simultaneously to provide the sense of "real life collaboration even in cyberspace" (Jaspers & Broeken, 2005, p. 2). In terms of goals, the main purpose of the *CRoCiCL* project focuses on exploring the "effects of visualization of social aspects of collaboration processes in CSCL [computer-supported collaborative learning]" (Jaspers & Broeken, 2005, p. 1). As part of this goal, the *VCRI* therefore focuses on participation awareness tools to help students visualize the participation and contributions of their group's members.

Integration of features to instantiate design principles and goals. Groups of two to four students work through a series of approximately eight lessons in a standard *VCRI* session. During this time, almost all software tools of the program are used and shared by group members. Argumentation and collaboration are encouraged heavily by *Cowriter*, *Chat, Shared Space, Participation*, and *Debate* tools.

The *Cowriter* is a shared word processor and collaborative text editor that allows students to create and/or edit the text simultaneously. This tool helps students write one document collaboratively through synchronous discussions. The proposed changes in the text are directly visible to all group members and the users can instantly give feedback to each other's edits. Also, teachers have access to the documents written by groups in the *Cowriter*. Therefore, teachers can observe the progress of the groups and respond the group members if necessary (Janssen et al., 2006; Broeken, 2006).

The *Chat* tool is a text-based collaborative tool that allows students to communicate in a simple but well-organized manner. Students use the *Chat* tool to interact with group members by instant messaging for real-time online meetings. The chat history of students is stored and can be reread at any time (Janssen et al., 2006; Broeken, 2006). The *Shared Space* is a special and advanced version of the *Chat* tool—it provides the same functionality but also includes visualizations, records the time interval of messages, and analyzes all messages sent by users (Janssen et al., 2006; Broeken, 2006). For example, the *Shared Space* tool saves the old topic and starts a new topic if group members do not submit messages for more than 59 seconds (Janssen et al., 2006; Broeken, 2006). Also, the *Shared Space* analyzes all messages using the *Dialogue Act Coding (DAC) filter*. Based on this online automatic coding, the *Shared Space* tool assesses whether the message suggests agreement or disagreement (Janssen et al., 2006; Broeken, 2006). Based on this analysis, the *Shared Space* dynamically represents the varying degree of discussion or agreement within the chat for the group.

The *Participation* tool determines the participation rates of the group members in terms of the degree to which each group member engages in the group's interaction. Each student is represented by a sphere. The distance of a sphere to the group's center indicates the number of messages sent by the student, compared to the other group members. The size of a sphere indicates the average length of the messages sent by a student in comparison with the other group members (Fig. 11.5). Participation within groups can be compared across the overall class community (Janssen et al., 2006). Similar to other tools, the *Participation* tool was also designed according to WYSIWIS principle. Each group member can monitor others' participation rates and compare his or her effort to that of other group members. This tool measures the contribution of the group members quantitatively without inferences about the quality of the participation (Broeken, 2006; Janssen et al., 2006). However, Broeken (2006) states that quantity of participation is also important and that high participation is essential to maintaining superior collaboration among group members.

The new *Debate* tool represents an argument visually as a battlefield of different standpoints (Fig. 11.6). With this shared tool, students specify the arguments they have found in external information sources and state whether each argument supports or rebuts one of the core positions. The *Debate* draws an instant diagram of "the complexity and the argumentative power of each position" (Broeken, 2006, p. 8). The complexity is visualized by the width of the frame around arguments and positions while the argumentative power is visualized by the interval between the center and location of arguments. Supporting contributions advance a position as a whole toward the center flag, whereas rebuttals retract the position. This allows users to evaluate how strongly the positions are supported. In this way, the *Debate*

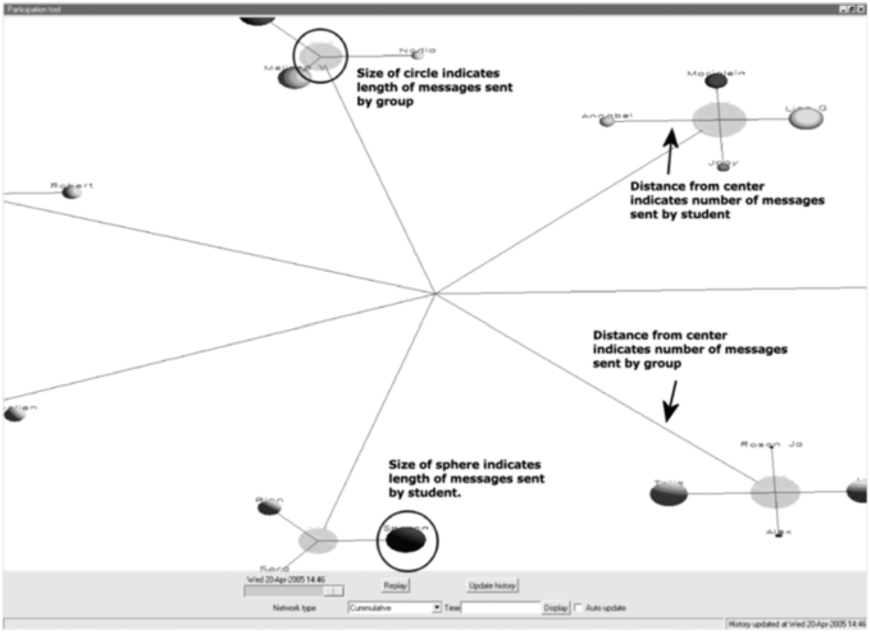

Fig. 11.5 VCRI participation tool

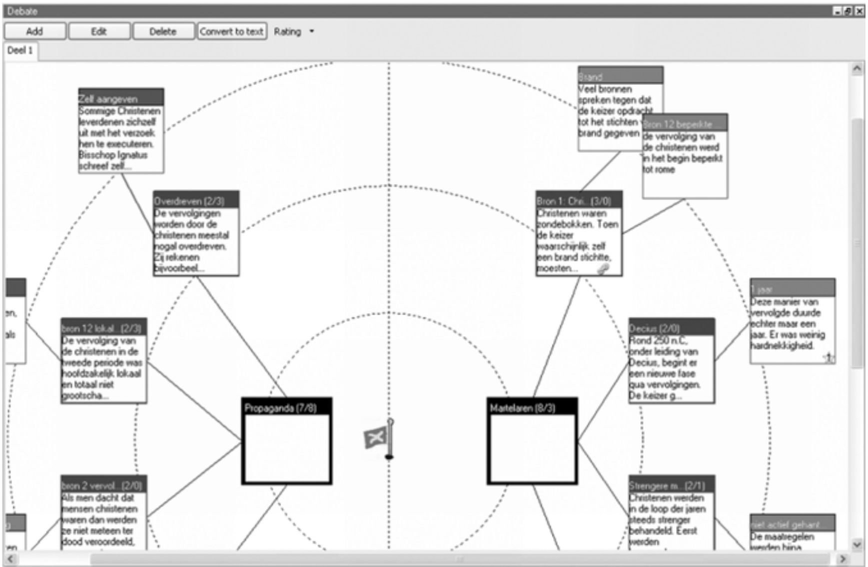

Fig. 11.6 VCRI debate tool

tool is expected to allow students to better evaluate different positions in authentic and complex contexts.

Research in VCRI. Research in the *VCRI* focuses on ways to support coordination processes between students as they collaborate on a project in a virtual groupware environment. Students need to coordinate their activities and their thinking in order to achieve their goals. From the perspective of the *VCRI* group, coordination involves three main processes: activation and sharing of knowledge and skills through participation in the collaboration process, creation of a common frame of reference through building awareness of differences and similarities in viewpoints and perspectives, and negotiation and coming to agreement through comparing and evaluating arguments and shared decision-making. The *Participation* tool, the *Shared Space*, and the *Debate* tool are meant to represent and support student's coordination processes on these three levels.

Concluding Comments and Future Directions

Learning environments currently include a broad range of specific instructional features to promote argumentation that can potentially facilitate active learning beyond what can be achieved in more traditional learning environments (Fabos & Young, 1999; Fischer, 2001; Marttunen & Laurinen, 2001; Pea, 1994; Roschelle & Pea, 1999; Schellens & Valcke, 2006). Major research questions and opportunities, however, require future investigation.

One promising core area for future work involves expanding upon one of technology-enhanced environments' greatest potential strengths—the ability to adapt scaffolding to meet the individual needs of students. A classic challenge in education involves the ratio of instructors to learners. As a result of this ratio, which is often sub-optimal in educational settings, learners frequently do not receive individualized customization of their learning experience. While research on groupwork and collaborative work has developed social structures to provide individualized attention to students in traditional face-to-face settings (e.g., Cohen, 1994), technology offers the opportunity to greatly enhance this process. All four of the example environments detailed in this chapter provide certain initial steps in this direction.

BGuILE individualizes students' experiences by allowing students to conduct inquiry as they choose and provides significant supports for them in analyzing the data through this process. In this sense, *BGuILE* does not customize scaffolding or the experience depending on the actions or contributions of the individual learner. Instead, *BGuILE* scaffolds students in pursuing directions of their choosing.

The *TELS Probing* project includes access to data and supports for analysis, though not to the degree found in *BGuILE*. The contribution of *Probing* with respect to individualization and customization of the learners' experience focuses more heavily on the capability of the environment to organize students into groups with others who have expressed different initial positions with respect to the phenomena under investigation. The analytic heuristic employed by the environment operates on values connected to the individual sentence fragments to assess an overall rating to each student's initial position. The heuristic can include logical and mathematical operators to determine values. The system does an effective job of placing students with others who have said something "different" even though the system could not reliably determine actual quality for summative assessment purposes. The approach therefore allows core customization of the activity structure by the technology based on the students' actions and contributions.

The *VCRI* environment provides customization in terms of participant awareness functionality. The *VCRI*, for example, provides students feedback on the number of contributions they make in comparison to other members of their group or to members of other groups in the class. Furthermore, the *VCRI* environment gives students feedback about group dynamic processes in terms of discussion and agreement. This participatory and group dynamic information is not only conveyed to the collaborating students but also to the teachers that supervise them. Future studies will focus on ways to support teachers in their supervision and coaching of collaborative learning.

The *CASSIS* environment stands to make one of the most cutting-edge steps in this area of customization and individualization by incorporating latent semantic analysis technology to drive customization of scaffolding. The *CASSIS* group has already demonstrated that such technology can code students' comments with essentially the same reliability as trained human coders. A next possible step could focus on integrating the technology in real-time into their environment to provide real-time feedback to learners or to actively modify levels and types of scaffolding.

So what does the future hold for technology-enhanced argumentation environments? As mentioned above, the opportunity to build intelligence into environments offers great potential affordances. By "intelligent environments" we refer to environments that have analytical real-time capabilities to support collaboration and arguments. How might incorporating intelligent analytical tools in real-time increase the power of online environments?

In the first section of this chapter we discussed the features and affordances of environments in terms of two main categories: facilitating collaborative argumentation and facilitating the construction of arguments and contributions. Embedding intelligent real-time analytical capabilities into environments could certainly enhance the affordances of both categories. Real time analytical capabilities could, for example, facilitate deep elaboration during individual argument construction or facilitate more equitable participation. Similarly, powerful opportunities will evolve in terms of enhancing participants' awareness of their positions, the ideas of others, and the quality of their argumentation. The organization of group composition could function based on nuanced analyses of students' positions. Environments could even shift groupings to introduce missing perspectives or critiques. Analytical capabilities might suggest specific data, visualizations, or experiments for students to consider in light of the arguments they construct. For example, a novice might get more hints than an expert.

Providing customized access to data could also help students strengthen or reconsider their positions. The environment might, for example, present evidence for the opposite position relative to the current position of a learner. Similar types of affordances might help students rethink their evaluation of data by providing new tools or perspectives. The *VCRI Debate* tool, for example, could compare the debate representations that groups construct to those made by other groups or to "expert" representations. This automatically derived comparative information could help students revise their representations. Clearly these supports could extend beyond structural issues into core conceptual issues regarding the content.

These future affordances will raise many important research questions beyond developing valid methods for measuring the quality, quantity, and nature of contributions. Future research will also need to consider carefully how to act on this information. How should instructional supports adapt to the information? How many suboptimal arguments, for example, should be required to trigger the "fading in" of a script? How many intermediate steps should be included between full instructional support and full freedom?

The potential benefits of increasing the intelligence of technology-enhanced argumentation environments (i.e., environments that have analytical real-time capabilities to support collaboration and arguments) are not limited to students. By integrating analytic frameworks to automate the logging and coding of students' actions and interactions in real-time, future versions of these environments could also provide teachers with better tools to monitor and scaffold multiple small groups of students working simultaneously on projects within their classes. Such environments might also model argumentation practices for the teachers themselves by helping the teachers interpret the argumentation practices of their students within the environment. Research has demonstrated that teachers' understandings of argumentation and pedagogical practices surrounding argumentation often do not reflect optimal levels of expertise for supporting students engaging in argumentation (Driver et al., 2000; Osborne et al., 2004). Technology-enhanced environments might provide a vehicle for supporting teachers' pedagogical practices as well as enhancing teachers' understanding of these pedagogical processes and the nature of argumentation.

In addition to research and development on the activity structures, features, and technology, other core issues require careful consideration in terms of practical as well as theoretical issues. Among the most important of the practical issues is the question of transfer of argumentation abilities from technology-enhanced environments to traditional unscaffolded contexts. While research on these environments has demonstrated their potential to successfully scaffold students in argumentation, few studies have examined issues of transfer into other contexts (e.g., Stegmann et al., 2004; Kollar et al., 2005). The value of these environments hangs heavily on their ability to support students' internalization of argumentation skills. Research on transfer should therefore play a central role in the advancement of the field.

In terms of theoretical issues, ongoing fundamental research needs to focus on core frameworks for argumentation and the analysis of argumentation in science education contexts. Sophisticated "intelligent" technology will provide little value unless it builds upon solid theoretical approaches to helping learners understand

and engage in argumentation. Similarly, sophisticated "intelligent" analytic technologies will provide little value unless they build on solid theoretical approaches for analyzing argumentation.

As our understandings of argumentation and the potential affordances of technology grow, with these caveats considered, we will have increasing opportunities to customize and individualize feedback and curricular structures in real-time to better support learners and teachers engaging in argumentation in classrooms around the world.

Acknowledgments The work for this chapter was partially funded by the US National Science Foundation (REC-0334199: TELS: The Educational Accelerator: Technology-Enhanced Learning in Science), the Deutsche Forschungsgemeinschaft (DFG; FI 792/2-2), and the Netherlands Organization for Scientific Research (nr. 411-02-121: CRoCiCL project).

References

Baker, M. (2003). Computer-mediated argumentative interactions for the co-elaboration of scientific notions. In J. Andriessen, M. Baker, & D. Suthers (Eds.), Arguing to learn: Confronting cognitions in computer-supported collaborative learning environments (pp. 47–78). Dordrecht, The Netherlands: Kluwer Academic.

Barron, B. (2003). When smart groups fail. The Journal of the Learning Science, 12, 307–359.

Bell, P. (1997). Using argument representations to make thinking visible for individuals and groups. In R. Hall, N. Miyake, & N. Enyedy (Eds.), Proceedings of the Second International Conference on Computer Support for Collaborative Learning (CSCL 1997) (pp. 10–19). Toronto, Canada: Toronto University Press.

Bell, P. (2004). Promoting students' argument construction and collaborative debate in the science classroom. In M. C. Linn, E. A. Davis, & P. Bell (Eds.), Internet environments for science education (pp. 115–143). Mahwah, NJ: Lawrence Erlbaum.

Bell, P., & Linn, M. C. (2000). Scientific arguments as learning artifacts: Designing for learning from the web with KIE. International Journal of Science Education, 22(8), 797–817.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). How people learn: Brain, mind, experience, and school. Washington: National Academic Press.

Broeken, M. (2006, May). *VCRI:* Using shared visualisations for collaboration. Paper presented at the 6th European Tcl/Tk Users Meeting, Bergisch Gladbach, Germany.

Carter, L. (2003). Argument in hypertext: Writing strategies and the problem of order in a nonsequential world. Computers and Composition, 20, 3–22.

Cavalli-Sforza, V., Lesgold, A., & Weiner, A. (1992). Strategies for contributing to collaborative arguments. Proceedings of the Fourteenth annual conference of the Cognitive Science Society, 755–760. Hillsdale, NJ. Lawrence Erlbaum.

Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. Cognitive Science, 5(2), 121–152.

Chi, M. T., Glaser, R., & Rees, E. (1982). Expertise in problem solving. In E. Sternberg (Ed.), Advances in the psychology of human intelligence (pp. 7–75). Hillsdale, NJ: Lawrence Erlbaum.

Clark, D. B., & Sampson, V. D. (2007). Personally seeded discussions to scaffold online argumentation. International Journal of Science Education, 29(3), 253–277.

Clark, D. B. (2004). Hands-on investigation in Internet environments: Teaching thermal equilibrium. In M. C. Linn, E. A. Davis., & P. Bell (Eds.), Internet Environments for Science Education. Mahwah, NJ: Lawrence Erlbaum.

Clark, D. B., & Sampson, V. (2005). Analyzing the quality of argumentation supported by personally seeded discussions. Paper presented at the annual meeting of the Computer Supported Collaborative Learning (CSCL) Conference, Taipei, Taiwan, June.

Clark, D. B., & Sampson, V. (in press). Assessing dialogic argumentation in online environments to relate structure, grounds, and conceptual quality. Journal of Research in Science Teaching.

Clough, E. E., & Driver, R. (1985). Secondary students' conceptions of the conduction of heat: Bringing together scientific and personal views. The Physical Educator, 20, 176–182.

Cognition and Technology Group at Vanderbilt. (1997). The Jasper Project: Lessons in curriculum, instruction, assessment, and professional development. Mahwah: Lawrence Erlbaum.

Cohen, E. G. (1994). Restructuring the classroom: Conditions for productive small groups. Review of Educational Research, 64, 1–35.

de Vries, E., Lund, K., & Baker, M. (2002). Computer-mediated epistemic dialogue: Explanation and argumentation as vehicles for understanding scientific notions. The Journal of the Learning Sciences, 11(1), 63–103.

Dillenbourg, P. (2002). Over-scripting CSCL: The risks of blending collaborative learning with instructional design. In P. A. Kirschner (Ed.), Three worlds of CSCL: Can we support CSCL? (pp. 61–91). Heerlen, NL: Open University of the Netherlands.

Dönmez, P., Rosé, C. P., Stegmann, K., Weinberger, A., & Fischer, F. (2005). Supporting CSCL with automatic corpus analysis technology. In T. Koschmann, D. Suthers, & T. W. Chan (Eds.), Proceedings of the International Conference on Computer Supported Collaborative Learning—CSCL 2005 (pp. 125–134). Taipei, Taiwan: Lawrence Erlbaum.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. Science Education, 84(3), 287–313.

Erickson, G., & Tiberghien, A. (1985). Heat and temperature. In R. Driver, E. Guesne, & A. Tiberghien (Eds.), Children's ideas in science (pp. 52–83). Philadelphia, PA: Open University Press.

Erkens, G., & Janssen, J. (2006). Automatic coding of communication in collaboration protocols. Proceedings of the 7th International Conference of the Learning Sciences (ICLS 2006), Bloomington, IN.

Erkens, G., Kanselaar, G., Prangsma, M., & Jaspers, J. (2003). Computer support for collaborative and argumentative writing. In E. De Corte, L. Verschaffel, N. Entwistle, & J. van Merriënboer (Eds.), Powerful learning environments: Unraveling basic components and dimensions (pp. 157–176). Amsterdam: Pergamon, Elsevier Science.

Fabos, B., & Young, M. D. (1999). Telecommunication in the classroom: Rhetoric versus reality. Review of Educational Research, 69(3), 217–259.

Fischer, F. (2001). Gemeinsame Wissenskonstruktion. Analyse und Förderung in computerunterstützten Kooperationsszenarien [Collaborative knowledge construction. Analysis and facilitation in computer-supported collaborative scenarios]. München, Germany: Ludwig-Maximilians-Universität München.

Fischer, F., Bruhn, J., Gräsel, C., & Mandl, H. (2002). Fostering collaborative knowledge construction with visualization tools. Learning and Instruction, 12, 213–232.

Fischer, F., Kollar, I., Mandl, H., & Haake, J. (Eds.) (2007). Scripting computer-supported collaborative learning. New York: Springer.

Fisher, C., & Larkin, J. H. (1986). Diagrams as working memory for scientific problem solving (Technical report). Pittsburgh, PA: Carnegie-Mellon University Department of Psychology.

Harrison, A. G., Grayson, D. J., & Treagust, D. F. (1999). Investigating a Grade 11 student's evolving conceptions of heat and temperature. Journal of Research in Science Teaching, 36(1), 55–87.

Hegel, G. W. F. (1965). Wissenschaft der Logik. Stuttgart, Germany: Frommann/Holzboog.

Hesse, F. (2007). Being told to do something or just being aware of something? An alternative approach to scripting in CSCL. In F. Fischer, I. Kollar, H. Mandl, J., & Haake (Eds.), Scripting computer-supported communication of knowledge - cognitive, computational and educational perspectives (pp. 91–98). New York: Springer.

Hoadley, C. (1999). Scaffolding scientific discussion using socially relevant representations in networked multimedia. Unpublished doctoral dissertation, University of California, Berkeley, CA.
Hoadley, C., & Linn, M. C. (2000). Teaching science through on-line peer discussions: SpeakEasy in the knowledge integration environment. International Journal of Science Education, 22(8), 839–857.
Hsi, S., & Hoadley, C. M. (1997). Productive discussion in science: Gender equity through electronic discourse. Journal of Science Education and Technology, 6(1), 23–36.
Hutchins, E. (1995). Cognition in the wild. Cambridge, MA: MIT Press.
Janssen, J., Broeken, M., Jaspers, J., Erkens, G., Kanselaar, G., & Kirschner, P. (2004). Computerized representation of coordination in collaborative learning. Retrieved April 28, 2007, from http://www.fss.uu.nl/edsci/index.php?option=com_content&task=view&id=92&Itemid=42Firefox HTML/Shell/Open/Command
Janssen, J., Erkens, G., Jaspers, J., & Broeken, M. (2006, June). Visualization of agreement and discussion processes during online collaborative learning. Paper presented at the 2nd Special Interest Meeting of EARLI SIGs Instructional Design & Learning and Instruction with Computers, Leuven, Belgium.
Janssen, J., Erkens, G., Jaspers, J., & Kanselaar, G. (2006, June/July). Visualizing participation to facilitate argumentation. Proceedings of the 7th International Conference of the Learning Sciences, Bloomington, IN.
Jaspers, J., & Broeken, M. (2005, May). VCRI: A groupware application for CSCL research. Paper presented at the European Tcl/Tk Users Meeting, Bergisch Gladbach, Germany.
Jermann, P., & Dillenbourg, P. (2003). Elaborating new arguments through a CSCL script. In J. Andriessen, M. Baker, & D. Suthers (Eds.), Arguing to learn: Confronting cognitions in computer-supported collaborative learning environments (pp. 205–226). Dordrecht, The Netherlands: Kluwer Academic.
Jermann, P., Soller, A., & Muehlenbrock, M. (2001). From mirroring to guiding: a review of state of art technology for supporting collaborative learning. Paper presented at the European Computer Supported Collaborative Learning Conference. (EU-CSCL'01), Maastricht, NL.
Joiner, R., & Jones, S. (2003). The effects of communication medium on argumentation and the development of critical thinking. International Journal of Educational Research, 39(8), 861–971.
King, A. (2007). Scripting collaborative learning processes: A cognitive perspective. In F. Fischer, I. Kollar, H. Mandl, & J. M. Haake (Eds.), Scripting computer-supported collaborative learning: Cognitive, computational, and educational perspectives. New York: Springer.
Kirschner, P. A., Buckingham Shum, S. J., & Carr, C. S. (Eds.) (2003). Visualizing argumentation: Software tools for collaborative and educational sense-making. London: Springer.
Kobbe, L., Weinberger, A., Dillenbourg, P., Harrer, A., Hämäläinen, R., & Fischer, F. (in press). Specifying computer-supported collaboration scripts. International Journal of Computer-Supported Collaborative Learning.
Kollar, I., Fischer, F., & Slotta, J. D. (2005). Internal and external collaboration scripts in web-based science learning at schools. In T. Koschmann, D. Suthers, & T. W. Chan (Eds.), Computer-supported collaborative learning 2005: The next 10 years! (pp. 331–340). Mahwah, NJ: Lawrence Erlbaum.
Kolodner, J. L., Schwarz, B., Barkai, R. D., Levy-Neumand, E., Tcherni, A., & Turbovsk, A. (1997). Roles of a case library as a collaborative tool for fostering argumentation. In R. Hall, N. Miyake, & N. Enyedy (Eds.), Proceedings of the 1997 computer support for collaborative learning (CSCL 97) (pp. 150–156). Hillsdale, NJ: Lawrence Erlbaum.
Kuhn, D., & Goh, W. W. L. (2005). Arguing on the computer. In T. Koschmann, D. Suthers, & T. W. Chan (Eds.), Computer supported collaborative learning 2005: The next 10 years! (pp. 125–134). Mahwah, NJ: Lawrence Erlbaum.
Kuhn, D., Shaw, V., & Felton, M. (1997). Effects of dyadic interaction on argumentive reasoning. Cognition and Instruction, 15(3), 287–315.
Leitão, S. (2000). The potential of argument in knowledge building. Human Development, 43, 332–360.

Lewis, E. L. (1996). Conceptual change among middle school students studying elementary thermodynamics. Journal of Science Education and Technology, 5(1), 3–31.
Linn, M. C., & Hsi, S. (2000). Computers, teachers, peers: Science learning partners. Mahwah, NJ: Lawrence Erlbaum.
Linn, M. C., Clark, D., & Slotta, J. D. (2003). WISE Design for knowledge integration. Science Education, 87(4), 517–538.
Marttunen, M. (1992). Commenting on written arguments as a part of argumentation skills: Comparison between students engaged in traditional vs. on-line study. Scandinavian Journal of Educational Research, 36(4), 289–302.
Marttunen, M., & Laurinen, L. (2001). Learning of argumentation skills in networked and face-to-face environments. Instructional Science, 29, 127–153.
Munneke, L., Andriessen, J., Kirschner, P., & Kanselaar, G. (2007, July). Effects of synchronous and asynchronous CMC on interactive argumentation. Paper to be presented at the CSCL 2007 Conference, New Brunswick, NY.
Norman, D. A. (1990). The design of everyday things. New York: Doubleday/Currency. Doubleday.
Norman, D. A. (1993). Things that make us smart. Reading, MA: Addison-Wesley.
Oestermeier, U., & Hesse, F. (2000). Verbal and visual causal arguments. Cognition, 75, 65–104.
Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in science classrooms. Journal of Research in Science Teaching, 41(10), 994–1020.
Pea, R. D. (1994). Seeing what we build together: Distributed multimedia learning environments for transformative communications. Special Issue: Computer support for collaborative learning. Journal of the Learning Sciences, 3(3), 285–299.
Pfister, H.-R. (2005). How to support synchronous net-based learning discourses: Principles and perspectives. In R. Bromme, F. Hesse, & H. Spada (Eds.), Barriers and biases in computer-mediated knowledge communication (pp.39–57). New York: Springer.
Reiser, B. J. (2002). Why scaffolding should sometimes make tasks more difficult for learners. In G. Stahl (Ed.), Computer support for collaborative learning: Foundations for a CSCL community. Proceedings of CSCL 2002 (pp. 255–264). Hillsdale, NJ: Lawrence Erlbaum.
Reiser, B. J., Tabak, I., Sandoval, W. A., Smith, B. K., Steinmuller, F., & Leone, A. J. (2001). BGuILE: Strategic and conceptual scaffolds for scientific inquiry in biology classrooms. In S. M. Carver & D. Klahr (Eds.), Cognition and instruction: Twenty-five years of progress (pp. 263–305). Mahwah, NJ: Lawrence Erlbaum.
Resnick, L. B., Salomon, M., Zeitz, C., Wathen, S. H., & Holowchak, M. (1993). Reasoning in conversation. Cognition and Instruction, 11, 347–364.
Rogoff, B. (1998). Cognition as a collaborative process. In D. S. Kuhn & R. W. Damon (Eds.), Cognition, perception and language, Vol. 2 (5th ed., pp. 679–744). New York: Wiley.
Roschelle, J., & Pea, R. (1999). Trajectories from today's WWW to a powerful educational infrastructure. Educational Researcher, 28(5), 22–25 and 43.
Sandoval, W. A. (2003). Conceptual and epistemic aspects of students' scientific explanations. Journal of the Learning Sciences, 12(1), 5–51.
Sandoval, W. A., & Millwood, K. A. (2005). The quality of students' use of evidence in written scientific explanations. Cognition and Instruction, 23(1), 23–55.
Sandoval, W. A., & Reiser, B. J. (2004). Explanation-driven inquiry: Integrating conceptual and epistemic supports for science inquiry. Science Education, 88, 345–372.
Scardamalia, M., & Bereiter, C. (1994). Computer support for knowledge-building communities. Journal of the Learning Sciences, 3(3), 265–283.
Schellens, T., & Valcke, M. (2006). Fostering knowledge construction in university students through asynchronous discussion groups. Computers & Education, 46(4), 349–370.
Schwarz, B. B., & Glassner, A. (in press). The role of CSCL argumentative environments for broadening and deepening understanding of the space of debate. In R. Saljo (Ed.), Information technologies and transformation of knowledge.
Stegmann, K., Weinberger, A., & Fischer, F. (2006). Facilitating argumentative knowledge construction with computer-supported collaboration scripts.

Stegmann, K., Weinberger, A., Fischer, F., & Mandl, H. (2004). Scripting argumentation in computer-supported learning environments. In P. Gerjets, P. A. Kirschner, J. Elen, & R. Joiner (Eds.), Instructional design for effective and enjoyable computer-supported learning. Proceedings of the first joint meeting of the EARLI SIGs Instructional Design and Learning and Instruction with Computers (CD-ROM) (pp. 320–330). Tuebingen: Knowledge Media Research Center.

Suthers, D. D., & Hundhausen, C. D. (2001). Learning by constructing collaborative representations: An empirical comparison of three alternatives. In P. Dillenbourg, A. Eurelings, & K. Hakkarainen (Eds.), European perspectives on computer-supported collaborative learning (pp. 577–592). Maastricht, NL: University of Maastricht.

Tabak, I. (1999). Unraveling the development of scientific literacy: Domain-specific inquiry support in a system of cognitive and social interactions, dissertation abstracts international Vol. A 60 (pp. 4323). Evanston, IL: Northwestern University.

Tabak, I. (2000). Exploring a range of student-directed inquiry processes and their influence on the construction of scientific conceptions. Paper presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, LA.

Tabak, I. (2004). Synergy: A complement to emerging patterns of distributed scaffolding. Journal of the Learning Sciences, 13(3), 305–335.

Tabak, I., & Baumgartner, E. (2004). The teacher as partner: Exploring participant structures, symmetry and identity work in scaffolding. Cognition and Instruction, 22(4), 393–429.

Tabak, I., & Reiser, B. J. (1997). Domain-specific inquiry support: Permeating discussions with scientific conceptions. In Proceedings of From Misconceptions to Constructed Understanding, Meaningful Learning Research Group, Ithaca, NY.

Tabak, I., Reiser, B. J., Spillane, J. P. (1999). BGuILE: Teachers, students and materials interacting to construct biological knowledge. In CILT99 the 1999 Annual CILT Conference, San Jose, CA.

Toulmin, S. (1958). The uses of argument. Cambridge: Cambridge University Press.

van Eemeren, F. H. (2003). A glance behind the scenes: The state of the art in the study of argumentation. Studies in Communication Sciences, 3(1), 1–23.

Veerman, A. (2003). Constructive discussions through electronic dialogue. In J. Andriessen, M. Baker, & D. Suthers (Eds.), Arguing to learn: Confronting cognitions in computer-supported collaborative learning environments (pp. 117–143). Amsterdam: Kluwer Academic.

Veerman, A. L., & Treasure-Jones, T. (1999). Software for problem solving through collaborative argumentation. In P. Coirier & J. E. B. Andriessen (Eds.), Foundations of argumentative text processing (pp. 203–230). Amsterdam: Amsterdam University Press.

Veerman, A. L., Andriessen, J. E. B., & Kanselaar, G. (1999). Collaborative learning through computer-mediated argumentation. In C. Hoadley & J. Roschelle (Eds.), Proceedings of the third conference on computer supported collaborative learning (pp. 640–650). Stanford, CA: Stanford University.

Voss, J. F., Tyler, S. W., & Yengo, L. A. (1983). Individual differences in the solving of social science problems. In R. F. Dillon & R. R. Schmeck (Eds.), Individual differences in cognition (pp. 205–232). New York: Academic.

Weinberger, A. (2003). Scripts for computer-supported collaborative learning. Effects of social and epistemic cooperation scripts on collaborative knowledge construction. Unpublished doctoral dissertation. Ludwig-Maximilians-University, Munich, Germany.

Weinberger, A., & Fischer, F. (2006). A framework to analyze argumentative knowledge construction in computer-supported collaborative learning. Computers & Education, 46(1), 71–95.

Weinberger, A., Ertl, B., Fischer, F., & Mandl, H. (2005). Epistemic and social scripts in computer-supported collaborative learning. Instructional Science, 33(1), 1–30.

Weinberger, A., Fischer, F., & Mandl, H. (2001). Scripts and scaffolds in text-based CSCL: fostering participation and transfer. Paper presented at the 8th European Conference for Research on Learning and Instruction, Fribourg, Switzerland.

Weinberger, A., Reiserer, M., Ertl, B., Fischer, F., & Mandl, H. (2005). Facilitating collaborative knowledge construction in computer-mediated learning with cooperation scripts. In R.

Bromme, F. Hesse, & H. Spada (Eds.), Barriers and biases in computer-mediated knowledge communication—and how they may be overcome (pp. 15–37). Boston, MA: Kluwer Academic.

Weinberger, A., Stegmann, K., Fischer, F., & Mandl, H. (2007). Scripting argumentative knowledge construction in computer-supported learning environments. In F. Fischer, I. Kollar, H. Mandl, & J. Haake (Eds.), Scripting computer-supported communication of knowledge—cognitive, computational and educational perspectives (pp. 191–211). New York: Springer.

Wolfe, C. R. (1995). Homespun hypertext: Student-constructed hypertext as a tool for teaching critical thinking. Special issue: Psychologists teach critical thinking. Teaching of Psychology, 22(1), 29–33.