Support for Workspace Awareness in Educational Groupware

Carl Gutwin[1], Gwen Stark[2] and Saul Greenberg[1]

[1] *Department of Computer Science, University of Calgary, Calgary, Alberta, Canada T2N 1N4*
E-Mail: [gutwin, saul] @cpsc.ucalgary.ca, Phone: +1 403 220-6087

[2]*Queen Elizabeth High School, Calgary Board of Education, Calgary, Alberta, Canada; E-Mail: gstark@cbe.ab.ca*

Abstract

Real-time educational groupware systems allow physically separated learners to work together in a shared virtual workspace at the same time. These systems do not yet approach the interaction richness of a face-to-face learning situation. In particular, one element poorly supported is *workspace awareness*: the up-to-the-minute knowledge a student requires about other students' interactions with the shared workspace. This awareness is essential if students are to learn and work together effectively. We present a framework of several types of awareness required by students in a collaborative learning situation, including their social, task, concept and workspace awareness. We then concentrate on workspace awareness, and describe how particular awareness requirements of students in group learning situations depend on the closeness of their tasks, and whether they are sharing the same view or have separate views into the workspace. From these requirements, we have prototyped several *awareness widgets* for educational groupware. These widgets help learners maintain awareness of other learners' locations when their views are separated, of other learners' activities in shared and separate view situations, and of other learners' past activities.

Keywords — awareness, widgets, groupware toolkits.

1. Introduction

Researchers in computer-supported collaborative learning (CSCL) attempt to understand and provide technological support for cooperative and collaborative learning [e.g. 17, 24, 21]. Within CSCL, one area of interest is groupware for real time distributed learning. These systems let geographically separate learners collaborate at the same time in a shared virtual *workspace*, a software environment containing learning and work artifacts that can be viewed and manipulated by anyone in the group; audio and perhaps video links are typically available as well. Educational groupware is becoming viable as local and wide area networks are put into place, which will allow its use both in networked classrooms and in distance learning.

Educational groupware does not yet provide the richness of face-to-face interaction. If such systems are to foster learning within a context of interaction, as has been advocated by educational theorists [e.g., 5, 3, 18], they must support the existing practices and processes of group learning. One practice critical to collaborative learning but not well supported in current educational groupware is *workspace awareness,* the up-to-the-minute knowledge a student needs about other students' interactions with the shared workspace [13]. Collaborating learners maintain this awareness by tracking information such as other learners' locations in the shared workspace, their actions, the interaction history, and their intentions. Workspace awareness is necessary for effective collaborative work, but also plays an integral part in how well an environment creates opportunities for collaborative learning.

This paper describes our investigation into the awareness requirements of collaborative learning, and specifically, how workspace awareness can be supported in groupware interfaces. Section 2 presents a framework for organizing the awareness requirements of a collaborative learning situation. Section 3 describes workspace awareness in more detail, and Section 4 describes our initial work in supporting workspace awareness through innovative interface components.

2. A Framework of Awareness

We have created a framework of awareness in collaborative learning in order to discuss the types of awareness that are used in a collaborative experience. We briefly explore the involvement of, and awareness requirements for the curriculum designer, teacher, evaluator and student in a successful collaborative activity. We then focus on types of student awareness which include: social, task, concept and workspace awareness. Workspace awareness in CSCL then becomes the focus of Sections 3 and 4. The skeleton of the framework, shown in Figure 1, creates a context for our later discussion of workspace awareness.

The success of a collaborative learning experience depends on the informed involvement of curriculum designer, teacher, evaluator, and students (Figure 1, left). The curriculum designer is responsible for the development of the activity and must apply the pedagogy

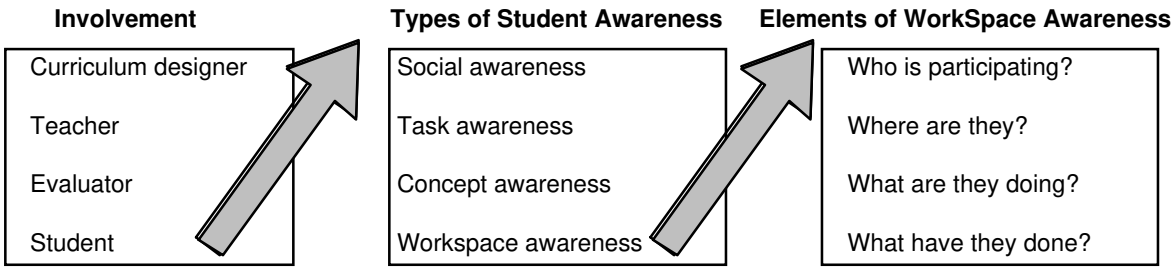

Figure 1. Framework of awareness in collaborative learning

of collaborative learning [e.g., 4, 30]. In addition, the curriculum designer must be aware of the objectives of the activity and must design the collaborative experience to support these objectives. The teacher is responsible for facilitating the activity and must work within the constraints of the group they are working with. The teacher must be aware of what the students are doing in the activity in order to help the students work towards the successful completion of the task. The evaluator is responsible for the evaluation of the process and must monitor the interactions that take place during the activity and must be aware of the outcome of the task. The students are responsible for working together to complete the collaborative task, and as part of the collaboration they must be aware of what is going on around them. Although every role and type of awareness in the process is important, the role of the student and the types of awareness they must have for a successful collaboration are the focus of the following discussion.

Goldman [12] identifies three types of student interaction: social, task, and conceptual. For each kind of interaction there is a corresponding type of awareness; in addition we add another type of awareness called workspace awareness (Figure 1, middle). *Social awareness* is the awareness that students have about the social connections within the group. *Task awareness* is the awareness of how the task will be completed. *Concept awareness* is the awareness of how a particular activity or piece of knowledge fits into the student's existing knowledge. Finally *workspace awareness* is the up-to-the-minute knowledge about other students' interactions with the shared workspace, suche as where other students are working, what they are doing, and what they have already done in the workspace. The questions in Table 1, organized into the categories described above, are examples of what students consider during the collaborative activity in order to be aware of what is happening in the group as they work on their task.

As suggested by the questions in Table 1, social awareness is inter-personal and perhaps best supported implicitly. For example, audio/video conferencing and media spaces [e.g., 6] can create communication opportunities that let people exchange necessary information with each other and negotiate their roles. Support for both task and concept awareness has been considered in cooperative learning [e.g., 16] and CSCL research; this support often provides explicit structures that students can use as scaffolds to assist them with organization or to help them stay focused on the learning tasks [30]. For example, cooperative learning assigns explicit roles to students and provides a clear outline of how the task is to be completed. In CSCL, knowledge-building environments such as CSILE [28] and CoVis' collaboratory notebook [20] provide structured message capabilities that guide students through the steps of a learning dialogue. Support for workspace awareness can be provided in part by *feedthrough* of what others are doing in the shared workspace. Although social, task, and concept awareness are important to the success of a collaborative learning experience, we now consider workspace awareness in more detail.

Social awareness	• What should I expect from other members of this group? • How will I interact with this group? • What role will I take in this group? • What roles will the other members of the group assume?
Task awareness	• What do I know about this topic and the structure of the task? • What do others know about this topic and task? • What steps must we take to complete the task? • How will the outcome be evaluated? • What tools/materials are needed to complete the task? • How much time is required? How much time is available?
Concept awareness	• How does this task fit into what I already know about the concept? • What else do I need to find out about this topic? • Do I need to revise any of my current ideas in light of this new information? • Can I create a hypothesis from my current knowledge to predict the task outcome?
Workspace awareness	• What are the other members of the group doing to complete the task? • Where are they ? • What are they doing? • What have they already done? • What will they do next? • How can I help other students to complete the project?

Table 1. Types of Student Awareness

3. Workspace Awareness

The rest of this paper deals specifically with workspace awareness. This section describes workspace awareness in more detail, and presents a third part of the framework that organizes group learning situations in terms of task and view proximity.

3.1 Workspace awareness in collaborative learning

As already mentioned, a student requires up-to-the-minute knowledge about other students' interactions with the shared workspace if they are to learn and work together effectively. This awareness is important in collaborative learning for two reasons. First, it reduces the overhead of working together, allowing learners to interact more naturally and more effectively. Second, it enables learners to engage in the practices that allow collaborative learning to occur.

As an example of how workspace awareness allows groups to be more effective, consider two learners who are reconstructing a poem given to them as individual, mixed-up lines. Each person maintains an awareness of where in the text the other is working, what they are doing, and what their intentions may be. Learner A may begin by picking out two lines that end with a certain rhyme. Learner B can ascertain A's activity by watching her work, even though she has not explicitly stated her chosen task. If B during the course of his own tasks comes across another line with the same rhyme, he can pick it out and give it to A, thereby assisting with her part of the task. This moment of collaborative effort is made possible because of workspace awareness, and though small, will be joined by many other similar moments of opportunistic collaboration. Taken together, these actions allow a group to be significantly more effective than an individual.

Workspace awareness also allows students to take advantage of the opportunities for interaction that make collaboration a valuable way to learn. In a collaborative learning situation, people may learn in a number of ways, such as:

- modelling the practices and skills of a more knowledgeable peer [e.g., 11, 8];
- identifying and resolving differences between conflicting ideas and theories [e.g., 9, 19];
- peer teaching, where one student assists or instructs another when appropriate [e.g., 31]; and
- constructing new shared meanings practices [23, 27].

Each of these mechanisms depends upon learners having a clear understanding of others' interactions with the workspace. For one learner to model another, they must be able to perceive the details of what others are doing. For one learner to propose a competing hypothesis at a point when it will be immediately relevant, they must know what other people's activities and intentions are. Peer teaching is similarly dependent upon knowing what another learner is working on and what they have already attempted, and building shared knowledge demands that a group understand what each other are doing and have done. Although the learning in a collaborative situation is dependent upon many factors, such as verbal interaction [22], it is the awareness of others and their activities that allows learners to initiate meaningful interaction at appropriate and opportune times.

3.2 Workspace proximity and workspace awareness

Another mechanism of collaborative learning that workspace awareness makes possible is to use the workspace artifacts as *conversational props* [2] that support learning dialogues. When the objects being discussed are visible to both learners, they can point and gesture to make clear the referents of their comments (called *deixis*), something that is difficult using language alone [3]. In addition, visible objects can act as a notational system [29] that extends the range and sophistication of concepts that the learners can discuss.

Although workspace awareness is often taken for granted in face-to-face collaborative learning situations, current groupware systems provide only a small amount of the information that students need to maintain it. We have been investigating how workspace awareness works in face-to-face situations, and how it can be supported in groupware applications. Our goal is to create real-time educational groupware that allows much of the same kinds of interaction, opportunities for collaboration, and opportunities for learning that are possible in a face-to-face situation.

The last part of our framework, shown in Figure 2, is a step towards this goal; it organizes group situations in a way that allows us to examine the specific mechanisms and information sources that people use to maintain workspace awareness. This organization considers two dimensions of group activity that involve the distance between learners: *view separation* and *task separation*. View separation is how closely group members share their views of the workspace. Learners will either be looking at the same set of objects or at different objects at any one time. Task separation considers how closely learners share activities. Although we assume they will be sharing an overall goal, learners may complete various low-level tasks as a group or as individuals. Figure 2 shows these two dimensions of group activity and, for each major area within the space, lists some of the workspace awareness questions that learners may need to answer.

Some of the collaborative learning situations defined in Figure 2 are outlined in the following section; we also describe our early investigations into supporting workspace awareness through groupware interfaces.

4. Widgets for Workspace Awareness

We are currently building general and reusable groupware interface widgets as part of GroupKit [25, 26],

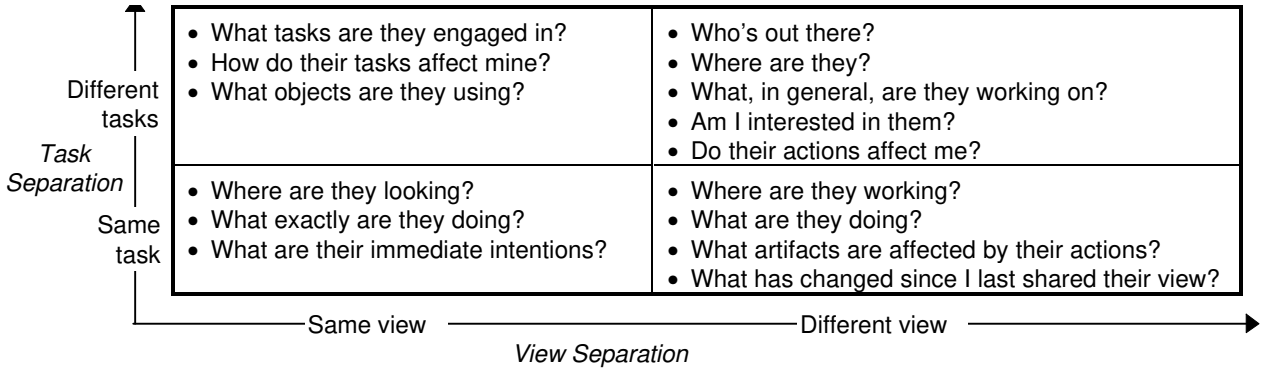

Figure 2. View and task proximity in collaborative situations

a groupware toolkit that streamlines the construction of multi-user applications. These widgets, designed from the framework described above, have been used in prototype groupware applications for exploring the issues involved in supporting workspace awareness. Educational groupware systems built with GroupKit are designed for multiple students in different locations, each with their own computer that is connected via a network. GroupKit supports interaction within a computational workspace, but does not directly supply audio or video communication; we assume that these channels will be provided through other technology.

The following sections describe three types of collaborative learning situations derived from Figure 2, bottom half: same task and same view; same task and different views; and same task with a mixed focus between views, where learners shift their attention between their individual and shared work. Within each situation, we describe GroupKit widgets and prototypes that support the maintenance of workspace awareness.

4.1 Same task, same view situations

In some collaborative learning situations, students work on the same low-level tasks, and focus on a small set of common objects. These situations involve close interaction and require awareness of the precise location and exact actions of other learners. For example, group creative writing involves partners who discuss and collaborate on each word and phrase of a poem; they need to know the exact context in which to interpret the other's comments and contributions. Peer editing is similar, where two students carry on a detailed discussion about a piece of writing. This activity illustrates the importance of supporting gestural communication—the two learners will use their text as a conversational prop, indicating pieces of text and possible changes by pointing and gesturing. Another example involves exploration and problem-solving in a physics microworld, where students work at the same task level, take part in each decision and action, and discuss the changes they see [7].

Same-view groupware systems (called strict 'what you see is what I see' or *strict WYSIWIS* [32]) must provide precise cues as to another learner's location and activity. GroupKit provides these cues in two ways. First, a designer is given control over how closely the screen actions are linked. For example, a shared drawing program might transmit the intermediate positions of an object as a student is moving it, or perhaps only transmit its new position after the move is completed. In a same-task same-view groupware application, we believe fine-grained screen linking gives learners a greater awareness of immediate changes to the workspace.

Multiple cursors [14] are a second means for supporting fine-grained awareness of location and activity in GroupKit. These show each person's mouse cursor and their movements displayed on every learner's screen. Multiple cursors allow gestural communication and give visual cues to a person's activity and intentions. Figure 3, for example, shows two students using a groupware sketchpad to present a weather cycle; their cursors are the two arrows labelled with their names.

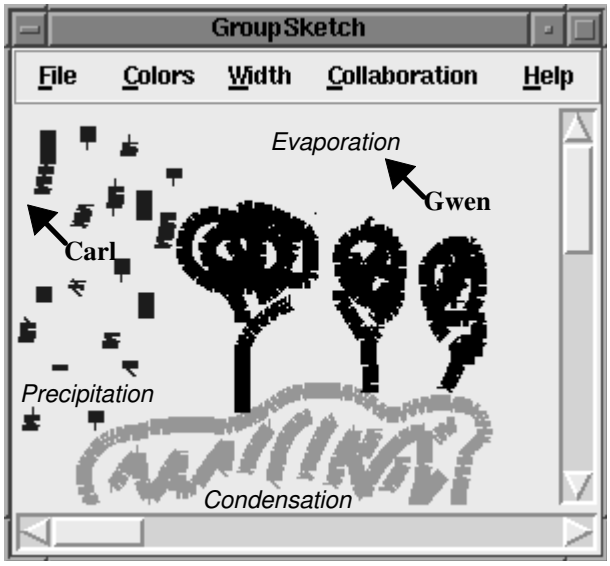

Figure 3. Multiple cursors in a group sketchpad

We have extended the idea of multiple cursors for situations where people see the same objects but with different presentations. The problem is that reproducing the literal movements of each person's mouse cursor across the displays will not show their actual position in the text. To address this problem, we have prototyped a *semantic cursor* that indicates the logical location of a

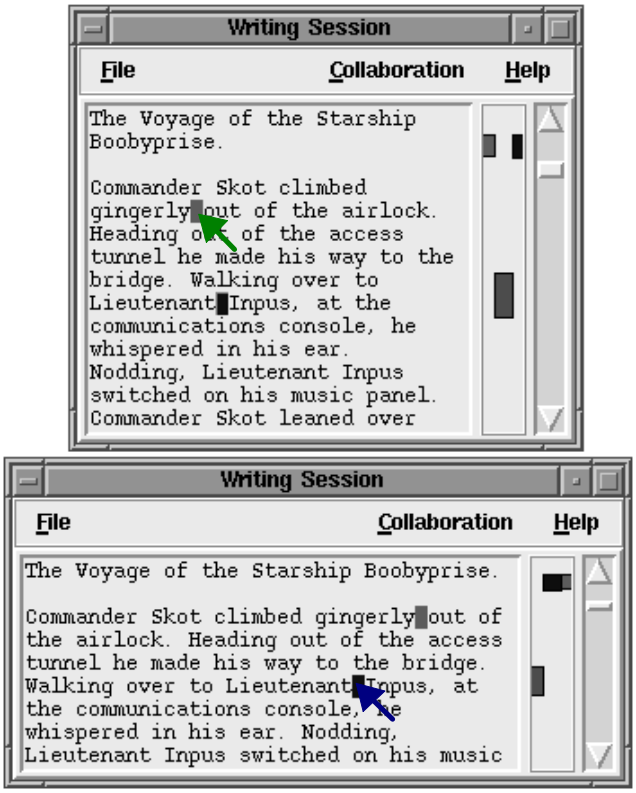

Figure 4. Two student's views into a peer writing session, showing semantic cursors and multi-user scroll bars.

person's cursor in the text rather than its screen position. For example, Figure 4 shows windows belonging to two students involved in a creative writing session; although both their views of their story begin at the same place, their text formatting differs. In the top window, the student's mouse cursor points to some text; this position is displayed as a semantic cursor in the bottom window by highlighting the letter (the space between 'gingerly' and 'out') rather than the actual screen location.

4.2 Same task, different view situations

Some learning situations involve coordinated action that occurs in different areas of the workspace. This kind of interaction can be seen when learners create a poster or collage: the learners are no longer making group decisions about each word or figure in the poster, and they may be working on different parts of the page. However, a sense of awareness about the others' activities is needed for coordination of effort and for making overall decisions. Another situation involves literature students who have the task of finding imagery of evil in Macbeth; each student looks for images of a different theme (blood, darkness, reversal, or decay). The students are working toward the same goal, and will need to keep track of each others' activities and progress, but they will all be looking at different parts of the play at any one time. A third example from our experience is that of social-studies students constructing a timeline to represent events in the history of a country. Since the timeline will be long, students will often have different

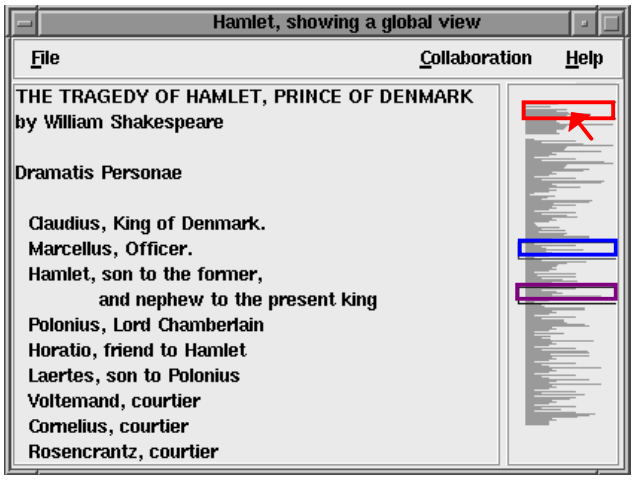

Figure 5. Global view of 3 student's locations in *Hamlet*

views onto the document. Again, they will still need information about where others are working, perhaps to offer additional information or to see what remains to be completed in the task.

Different views into a common workspace (called *relaxed WYSIWIS* [32]) imply that the requirements for workspace awareness will be coarser than in a strict WYSIWIS situation. Awareness of fine-grained actions like the movement of someone's pointer may be less important, but awareness of location with respect to the entire document, and awareness of activities at a higher level, are more important. However, there are also cases where learners may need some kinds of detailed information about others' activities, such as the kind of information that is gathered through peripheral vision or hearing in a face-to-face situation.

We have designed both a multi-user scrollbar and a global display widget in GroupKit to provide information about both location and activity in relaxed WYSIWIS systems. Figure 4 shows the multi-user scrollbar and how it supports workspace awareness by pinpointing other learners' relative locations within the document. The right-most control acts like a standard scrollbar, and lets each student manipulate their own view. To its left are several uniquely-colored vertical bars showing the relative viewport of all three learners in this session. In this case, Figure 4 shows two learners with aligned views (whose windows are both shown), and a third learner viewing text near the end of the document. The position and size of each bar is continuously updated as learners scroll through the document or change their window size. If a learner wishes to match their view with someone else's, they need only drag their scroller until it is level with the other's indicator bar.

The global view display, illustrated in Figure 5, is a richer version of the multi-user scrollbar. It shows a miniature of the entire document (the right window), overlaid with colored boxes that represent the viewports of all students into the document. The miniature provides structural cues about the document that help the student

understand where their collaborators are working and what they are doing. The colored viewport boxes are also active interface objects: a student scrolls to a new location by dragging their box with the mouse, and the text window on the left is updated accordingly. In the figure, for example, the local student is reading the beginning of Hamlet, and her box is drawn at the top of the global view. Two other students are further on in the text. As in the multi-user scrollbar, she can make her view congruent with another student's view by dragging her box to the same level as the other's box.

Supporting fine-grained awareness of activity in different-view situations is more difficult than when learners can see the same objects, since they can no longer see the other person's cursor or how the objects are being changed. Limitations on screen space discourage the simple solution of showing complete duplicates of every student's view. Instead, we have prototyped a 'what you see is what I do' (*WYSIWID*) display. This widget shows only the immediate context around another learner's cursor, which is a subset of their view. This is illustrated in Figure 6, where a person sees not only their main view (left side), but also part of another student's view (top right corner). The remote view is always centered around the other student's cursor; rather than showing cursor movement, the background is panned instead. Since most actions in graphical applications involve the mouse cursor, this local-view display can show in detail what others are doing, yet consume only modest screen real estate.

4.3 Same task, mixed focus situation

A third kind of collaboration flips between same-view and different-view situations. We call this kind of interaction *mixed focus collaboration*: individual and shared activities within the workspace are interleaved, and learners periodically shift their attention back and forth between separate and shared views of the workspace. In practice, many collaborative learning situations will have elements of mixed focus collaboration. In the examples described so far, the poem reconstruction, the collaborative poster, and the group effort in finding imagery in *Macbeth* would all involve periods of individual and shared activity.

While mixed focus collaboration can be partially supported by the techniques discussed in the previous two sections, it presents additional requirements for workspace awareness. In particular, a learner may need to bring oneself up to date on what the other person has been doing—the changes they have made and where they have been—before rejoining their view and starting a period of shared work.

Existing techniques such as adding change bars to a document or calculating the difference between two versions ('diffing') can only provide some of this information, and usually only for text documents. We have designed a few widgets to investigate awareness of a group's recent actions. For example, to support awareness of where other learners have been working, we have prototyped a history mechanism to a global view display, as shown in Figure 7. In addition to showing another learner's current viewport, the widget tracks their location over time. Moving the slider at the bottom of the window plays back the movement of another person's viewport (displayed as a moving outline rectangle), and also indicates where they stopped for a while (shown as a filled rectangle).

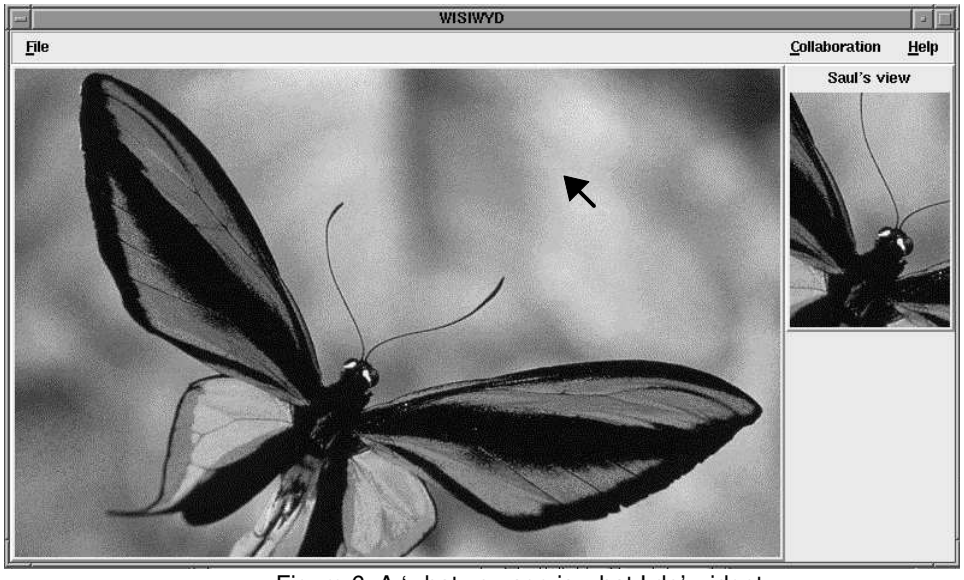

Figure 6. A 'what you see is what I do' widget

5. Related Work and Further Research

Educational groupware draws on work done in the field of computer-supported cooperative work [10]; several CSCW projects have considered the issues involved in creating real-time distributed systems, and some have touched on the concept of workspace awareness. For example, the multi-user scrollbar and a global-view device called a gestalt viewer were first seen in the SASSE text editor [1]; other systems have used tools like activity indicators [32, 10] to keep people informed. One branch of CSCW research that has promise for supporting both social and workspace awareness looks at mixing video signals of learner's hands or faces together with a computational representation of the shared workspace [15].

Our investigations into support for workspace

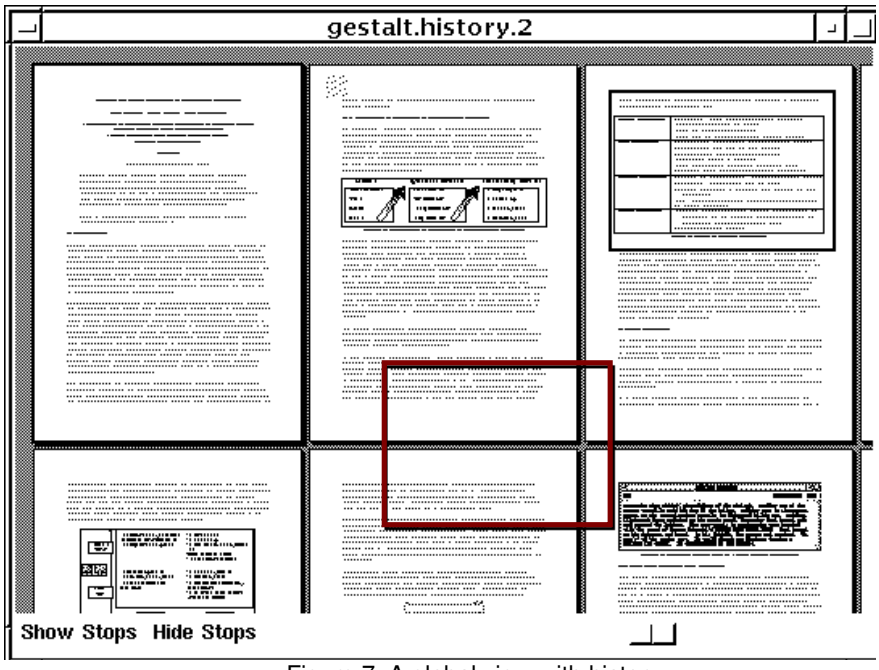

Figure 7. A global view with history.

awareness will continue in several directions. We plan to conduct observational experiments to gather data about what mechanisms people use to maintain workspace awareness in particular situations like mixed focus collaboration. From this knowledge, we will form design principles for new groupware widgets. As well, we are identifying overall issues that affect the design and implementation of these techniques, including:

- the trade-off between being well informed about other learners' activities but being distracted by that information from their individual tasks;
- allowing learners to exert some control over the awareness information that others receive about them;
- whether we can go beyond existing face to face practices, and create new awareness mechanisms that augment, rather than just replace, what people normally expect.

6. Conclusion

This paper has outlined a framework that sets workspace awareness in a context of awareness requirements for collaborative learning. We presented a way to organize collaborative situations in terms of task and view separation, and introduced several interface components that support the maintenance of workspace awareness in educational groupware. The components are useful for same view situations, for different view situations, and also for mixed focus interaction.

Acknowledgments. This research is supported by the National Engineering and Research Council of Canada, and by Intel Corporation. Shannon Jaeger and Mark Roseman contributed to the widget designs. Special thanks to Ruby Loo, Kar-Ling Cheng, and Andrea Byrne for several long-distance favours.

Availability. GroupKit is available via anonymous ftp, and a world wide web page documents the system:

site:	ftp.cpsc.ucalgary.ca
directory:	pub/projects/grouplab/software
http:	http://www.cpsc.ucalgary.ca/projects/grouplab/home.html

References

1. Baecker, R.M., Nastos, D., Posner, I.R. and Mawby, K.L. (1993) "The User-Centred Iterative Design of Collaborative Writing Software." In *Proc ACM INTERCHI'93 Conference on Human Factors in Computing Systems*, p399-405.
2. Brinck, T. and Gomez, L. (1992) "A Collaborative Medium for the Support of Conversational Props." In *Proc ACM Conference on Computer Supported Cooperative Work*, p171-178, Toronto.
3. Brown, J.S., Collins, A. and Duguid, P. (1989) "Situated Cognition and the Culture of Learning." In *Educational Researcher*, **18**(1), p32-42.
4. Brufee, K. (1983) "Teaching Writing through Collaboration." In *Learning in Groups: New Directions for Teaching and Learning*, C. Bouton and R. Garth ed., p23-29, San Fransisco CA, Jossey-Bass.
5. Bruner, J. (1985) "Vygotsky: a Historical and Conceptual Perspective." In *Culture, Communication, and Cognition: Vygotskian perspectives*, J.V. Wertsch ed., Cambridge, U.K., Cambridge University Press.
6. Buxton, W. (1992) "Telepresence: Integrating Shared Task and Person Spaces." In *Proc Graphic Interface '92*, p123-129, Morgan Kaufmann.

7. Cockburn, A. and Greenberg, S. (1995) "TurboTurtle, a Collaborative Microworld for Exploring Newtonian Physics." In *Proc ACM Conference on Computer Supported Collaborative Learning*.
8. Collins, A., Brown, J.S. and Newman, S.E. (1989) "Cognitive Apprenticeship: Teaching the Crafts of Reading, Writing, and Mathematics." In *Knowing, Learning, and Instruction: Essays in Honor of Robert Glaser*, p453-494, L. Resnick ed., Hillsdale, NJ, Lawrence Erlbaum Associates.
9. Doise, W. and Mugny, G. (1984) *The Social Development of the Intellect*, Pergamon Press, NY.
10. Ellis, C., Gibbs, S. and Rein, G. (1991) "Groupware: Some Issues and Experiences." *Comm ACM*, **34**(1), p38-58.
11. Forman, E.A. and Cazden, C.B. (1985) "Exploring Vygotskian Perspectives in Education: the cognitive value of peer interaction." In *Culture, Communication, and Cognition: Vygotskian perspectives*, J.V. Wertsch ed., Cambridge, U.K., Cambridge University Press.
12. Goldman, S.V. (1992) "Computer Resources for Supporting Student Conversations about Science Concepts." *SIGCUE Outlook*, **21**(3), p4-7.
13. Gutwin, C. and Greenberg, S. (1995) "Support for Group Awareness in Real-Time Desktop Conferencing." In *Proc 2nd New Zealand Computer Science Research Student's Conference*, April 18-21, University of Waikato, Hamilton, New Zealand.
14. Hayne, S., Pendergast, M., and Greenberg, S. (1993) "Implementing Gesturing with Cursors in Group Support Systems." In *JMIS*, **10**(3), p43-61.
15. Ishii, H. and Kobayashi, M. (1992) "ClearBoard: A Seamless Medium for Shared Drawing and Conversation with Eye Contact." In *Proc ACM CHI Conference on Human Factors in Computing Systems*, p525-532, Monterey, California.
16. Johnson, D. and Johnson, R. (1985) "Cooperative Learning: One Key to Computer-Assisted Learning." *The Computing Teacher*, **13**(2), p11-13.
17. Koschmann, T.D. (1994) "Toward a Theory of Computer Support for Collaborative Learning." *The Journal of the Learning Sciences*, **3**(3), p219-225.
18. Lave, J. and Wenger, E. (1991) *Situated Learning: Legitimate Peripheral Participation*, Cambridge University Press, Cambridge, U.K.
19. Messer, D. and Light, P. (1991) "The Role of Collaboration and Feedback in Children's Computer-based Learning." *Journal of Computer-assisted Learning*, **7**(2), p156-159.
20. O'Neill, D.K. and Gomez, L.M. (1994) "The Collaboratory Notebook: A Networked Knowledge-Building Environment for Project Learning." In *Proc Ed-Media*, Vancouver, Canada.
21. Pea, R. and Gomez, L. (1992) "Distributed Multimedia Learning Environments: Why and How?" *Interactive Learning Environments*, **1**(2), p73-110.
22. Repman, J. (1993) "Collaborative, Computer-based Learning: Cognitive and Affective Outcomes." *J of Educational Computing Research*, **9**(2), p149-163.
23. Roschelle, J. (1992) "Learning by Collaborating: Convergent Conceptual Change." *The Journal of the Learning Sciences*, **2**(3), p235-276.
24. Roschelle, J. and Clancey, W.J. (1992) "Learning as Social and Neural." *Educational Psychologist*, **27**(2).
25. Roseman, M. and Greenberg, S. (1995) "Building Real Time Groupware with GroupKit, A Groupware Toolkit." Accepted to *ACM Transactions on Computer Human Interaction.* Also as technical report 95/559/11, Department of Computer Science, University of Calgary, Canada.
26. Roseman, M. and Greenberg, S. (1992) "GroupKit: A Groupware Toolkit for Building Real-time Conferencing Applications." In *Proc ACM Conference on Computer Supported Cooperative Work*, p43-50, Toronto, Ontario.
27. Scardamalia, M. and Bereiter, C. (1992) "An Architecture for Collaborative Knowledge Building." In *Computer-Based Learning Environments and Problem Solving*, p41-66, E. de Corte, E. Linn, H. Mandl and L. Verschaffel eds., NY, Springer-Verlag.
28. Scardamalia, M., Bereiter, C., Brett, C., Burtis, P., Calhoun, C. and Smith Lea, N. (1992) "Educational Applications of a Networked Communal Database." *Interactive Learning Environments*, **1**(2), p45-71.
29. Singer, J., Behrend, S. D. and Roschelle, J. (1988) "Children's Collaborative Use of a Computer Microworld." In *Proc ACM Conference on Computer Supported Cooperative Work*, p271-281, Portland, Oregon.
30. Slavin, R. (1983) *Cooperative Learning*, Longman, NY.
31. Smith, B.L. and MacGregor, J.T. (1992) "What is Collaborative Learning?" In *Collaborative Learning: A Sourcebook for Higher Education*, p10-29, A.S. Goodsell, M.R. Maher and V. Tinto ed., Univ Park, PA, National Center on Postsecondary Teaching.
32. Stefik, M., Bobrow, D., Foster, G., Lanning, S. and Tatar, D. (1987) "WYSIWIS Revised: Early Experiences with Multiuser Interfaces." *ACM Trans Office Information Systems*, **5**(2), p147-167.