Collaborative Websites Supporting Open Authoring

Mark Guzdial

EduTech Institute and GVU Center

College of Computing

Georgia Institute of Technology

Atlanta, GA 30332-0280

404-894-5618

guzdial@cc.gatech.edu

Submission to *Journal of the Learning Sciences*

Collaborative Websites Supporting Open Authoring

Abstract

The potential learning benefits of the Web are diminished due to the complexity of creating interactive, collaborative Web-based applications. The CoWeb is a collaborative website which allows users to create collaborative applications with great flexibility. The CoWeb facilitates *open authoring* where any user can edit any existing page or creating new pages. Using the CoWeb, both teachers and students have created a wide variety of educational applications. For teachers, the CoWeb is empowering. For students, the CoWeb can lead to a cultural change where they take on higher levels of agency. The CoWeb can be used to providing *dynamic scaffolding*, where the source of support is distributed across people and media and where the support changes over time. The paper describes the CoWeb and some of the applications that teachers and students create with an open authoring environment.

Collaborative Websites Supporting Open Authoring

I. Introduction: Supporting Open Authoring on the Web

There seems to be relatively little argument that the Web could have educational benefits. Creating Web pages can be a motivator for students because of the world wide audience that a Web page can reach (Blumenfeld et al., 1991). Web pages can offer user interaction, so that they are more than just passive conveyors of information. Combining the wide audience and interaction, it can enable collaboration (Guzdial et al., 1997) which can support complex and motivating student work (Blumenfeld et al., 1991) and the development of improved, shared conceptualizations (Jeong & Chi, 1997; Roschelle, 1992).

Making the Web *actually* work for learning is a real challenge. The barriers to using the Web for educational applications are considerable. Using the Web requires mastery of concepts such as HTML, servers, FTP of files, and CGI scripting or Java applets for interactivity. While the potential to utilize the Web as a powerful medium for communication is real, the HTML language for creating these links and for formatting text and graphics serves as a gatekeeper to prevent the least technical users from accessing the Web's potential. The interactive aspects of the Web are particularly complicated for

teachers and students to access, requiring complicated programming of CGI scripts or Java applets. In short, the most powerful aspects of the Web also have the greatest barriers to students and teachers.

However, the most interesting question about the use of the Web for learning is not *how* to resolve the challenge, but *what* happens if the challenge is met. If students and teachers could easily author Web documents, what would they author? If the authoring were *open* so that any user could edit any page and create any pages, how might that facility be used? Most importantly, how would it change student attitudes or classroom practice?

The focus for this paper is the *what* question. We (the author and his collaborators) have placed into classroom use a very simple forum for communication and collaboration called the *CoWeb*, for **Co**llaborative **Web**site. The CoWeb is not an advanced technology, and it does not support the creation of interactive elements the way that other tools do, e.g., AgentSheets (Repenning, 1994). Rather, the CoWeb supports a simple but powerful notion of *open authoring*: Any user can edit any page, and any user can create any page, with links from and to any other page. There is no distinction enforced in the software between teachers and students, and there is no explicit scaffolding built into the tool to structure what students do, how they do it, or even how they learn with the space. On the other hand, what the CoWeb does do is to make it as easy as possible for teachers and students to create collaborative Web-based activities. For this one aspect of the potential of the Web, the CoWeb does resolve the issue of providing access with very few interface

barriers. Thus, with the CoWeb, we can ask what teachers and students will do when openly authored Web pages become a matter of course.

We originally began exploration of the CoWeb as an extension of our research on anchored discussion and collaboration (Guzdial, 1997; Guzdial & Turns, 1999). We had shown that collaboration spaces directly linked to media of interest to students (*anchors*) tended to create more sustained discussion than traditional classroom newsgroup discussions. But in our work, the anchors were always created by teachers. Was it the anchor, or the fact that the teacher said to go there? Could students create anchors? Through the CoWeb, we were able to explore how other students might discuss anchors created by peer students.

There are other good reasons to explore open authoring:

- Open authoring supports *constructionism*, a pedagogical approach which says that students' construction of their own understandings (constructivism) happens "especially felicitously" when the students are engaged in constructing public artifacts (Papert, 1991). *Project-based learning* is a well-defined form of constructionism where students learn in classroom settings through the creation of shared, public externalizations of their knowledge (Blumenfeld et al., 1991; Krajcik, Blumenfeld, Marx, & Soloway, 1994; Soloway, Krajcik, Blumenfeld, & Marx, 1996b). When students can create artifacts as interesting and as public as anything that the teacher can create, the potential for interesting projects and for learning is enhanced.

- Open authoring shifts agency in the learning setting. Scardamalia and Bereiter have noted this important shift in their work with students using CSILE, a collaborative knowledge-construction environment. They note that traditional classrooms have teachers (experts) asking students questions that the teacher already knows the answer to. In most adult settings, and in classrooms where students have higher levels of agency, the students ask questions of experts (teachers and others) at the point when the student really wants the answer (Scardamalia & Bereiter, 1991). An open authoring environment enables this same kind of shift of agency, because students become the creators of activities and even informed consumers of the teacher's created activities.

The focus of this paper is on what teachers, students, and even researchers are doing when the barriers to open authoring are removed. In the next section, the CoWeb is introduced. The following section lists several of the activities that have been implemented on the CoWeb in the first couple years of its use in classes. Most of the activities are drawn from experience at Georgia Tech where about a dozen classes use the CoWeb each term. We have undertaken an early study of student attitudes toward the CoWeb and open authoring, and the results of this initial study are presented. Finally, some of the characteristics of successful CoWeb activities are presented. The point of this paper is to show that open authoring has unleashed a great deal of teacher, and student, creativity, and it seems to be having an impact on student attitudes.

II. CoWeb: Open Authoring on the Web

The basic idea behind the CoWeb is that any page is directly editable by any reader of that page and that any editor can create pages in the website.. Ward Cunningham is the inventor of this kind of website, as implemented in his WikiWikiWeb[1]. The CoWeb was designed as a kind of WikiWikiWeb using a webserver and toolkit I wrote called the Pluggable WebServer (PWS), based on work by Georg Gollman. The PWS is written in Squeak[2], a new form of the Smalltalk programming language (Ingalls, Kaehler, Maloney, Wallace, & Kay, 1997), so my version of the tool was originally called *Swiki* for Squeak-Wiki. The CoWeb is a more descriptive term of the end product, however, and has become the more common name. The PWS and the CoWeb tool have been improved dramatically by Ted Kaehler, Lex Spoon, Bijan Parsia, and others on the Web—making the CoWeb tool itself the product of an open authoring effort.

A CoWeb looks like a fairly traditional web site. Figure 1 is a screenshot of the front page of a CoWeb[3]. A CoWeb page can have essentially any kind of media or formatting that any other Web page can. A key feature of a CoWeb page, however, is the link in the upper left corner of Figure 1, “Edit this Page.”

When the reader of the page seen in Figure 1 clicks “Edit this Page,” she gets a new page that looks like Figure 2. The text appearing in the scrollable text area is actually the

---

[1] http://c2.com/cgi-bin/wiki

[2] http://squeak.cs.uiuc.edu

[3] http://pbl.cc.gatech.edu/cs2390/1.html

text of the page in Figure 1. The reader can edit this text—perhaps correcting some of the text, adding new text, making a comment, or linking to other pages within the CoWeb or elsewhere on the Web. When the user clicks the "Save" button, the page will be updated to reflect the changed text.

While editing a CoWeb page, users can create new pages. The user types a title for the new page (e.g., "My New Page") between asterisks (e.g., "*My New Page*") in the text area. When the page is saved, the title text (without asterisks) becomes a link. Clicking on the link opens the new, blank page. The user can then edit the new page by choosing the "Edit this Page" link. The user never has to deal with creating files or making the files accessible by a Web server.

Editing a page is a simplified form on editing a traditional Web page.

- As can be seen in Figure 2, CoWeb pages can be written using the same editing conventions used in email. Text can be entered as paragraphs (with or without pressing the return key at the end of the line), and a blank line separates paragraphs.
- Links to existing CoWeb pages are entered the same as new pages, with the title between asterisks. For example, *Front Page* entered on a CoWeb page would create a link to the top of the CoWeb site.
- Links to external Web pages are entered as the URL between asterisks, e.g., *http://www.cc.gatech.edu*. When saved, the link becomes a hyperlink that will take the user to the page at the given URL address.

- Images can also be incorporated into a CoWeb page using the same technique as creating links. The user enters the URL for the image between asterisks (e.g., *http://myserver.edu/myimage.gif*). When the page is displayed, the image will be fetched and displayed in the place of the image URL on the page. In more recent forms of the CoWeb, images can be uploaded directly to the CoWeb through an Attachments page, and a simplified form of reference is supported (e.g., *!myimage.gif!*).
- If the user does know any HTML, it can be intermixed with CoWeb-style text. As the user learns more sophisticated HTML (e.g., tables and even JavaScript), these can be entered into the page as well.

The CoWeb provides supports that facilitate use of the site by users, all of which were originally invented in Cunningham's WikiWikiWeb.

- A “Recent Changes” page is available for every CoWeb. It lists each page by title in the CoWeb by the day on which it was changed in reverse chronological order (i.e., today is at the top). “Recent Changes” serves as an automatic table of contents for the CoWeb and as a mechanism to alert users when another user has changed an existing page or created a new page.
- The entire CoWeb is searchable from any page in the CoWeb. This enables users to find what others have done, even if long ago and far down the “Recent Changes” list.

The CoWeb offers little in the way of security. Each version of each page is saved, so it is possible for an administrator to restore a page to any previous point of time[4]. Without the adminstrator, the user can access any of the last three versions of a page to recapture previous content. The most powerful security measure on the CoWeb is the power of social conventions. People do not normally destroy one another's contributions. People generally identify themselves with their contributions. On the original Wiki by Ward Cunningham, users make sure that ideas are not lost—if someone inadvertently (or otherwise) deletes important text, "housekeepers" make sure that the text is repaired. In this way, even protection becomes a collaborative task (Cunningham, 1998).

[4] With the falling prices of hard disks, the approach of saving everything is not as wasteful as it seems. The largest CoWeb to date, over 1500 Web pages, only takes up 50M of space with all versions of every page. The disk containing that CoWeb can store two gigabytes of data (a fairly small disk these days), meaning that the CoWeb can grow 40 times larger before it becomes cramped for space.

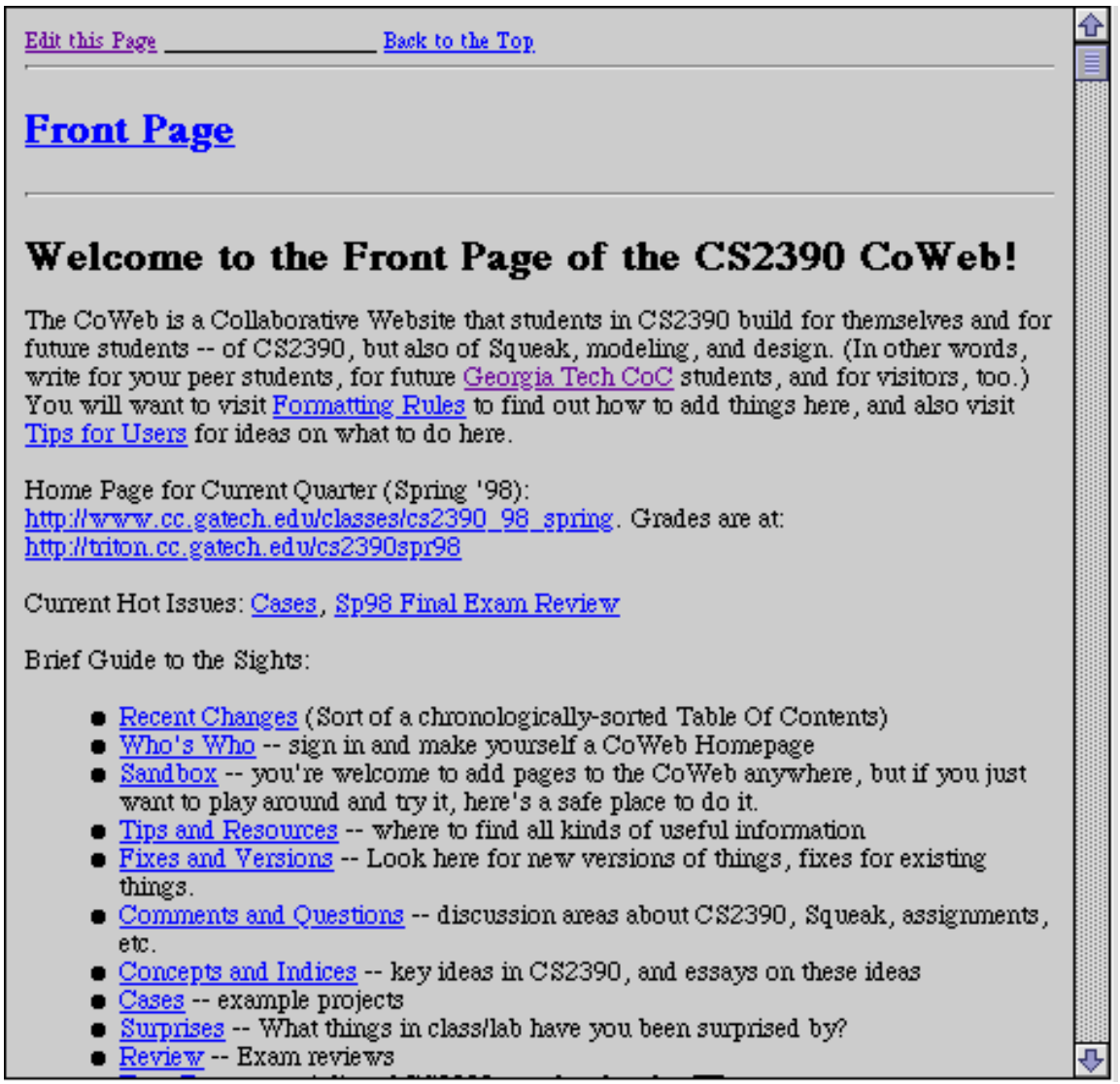

Figure 1: A Page in a CoWeb

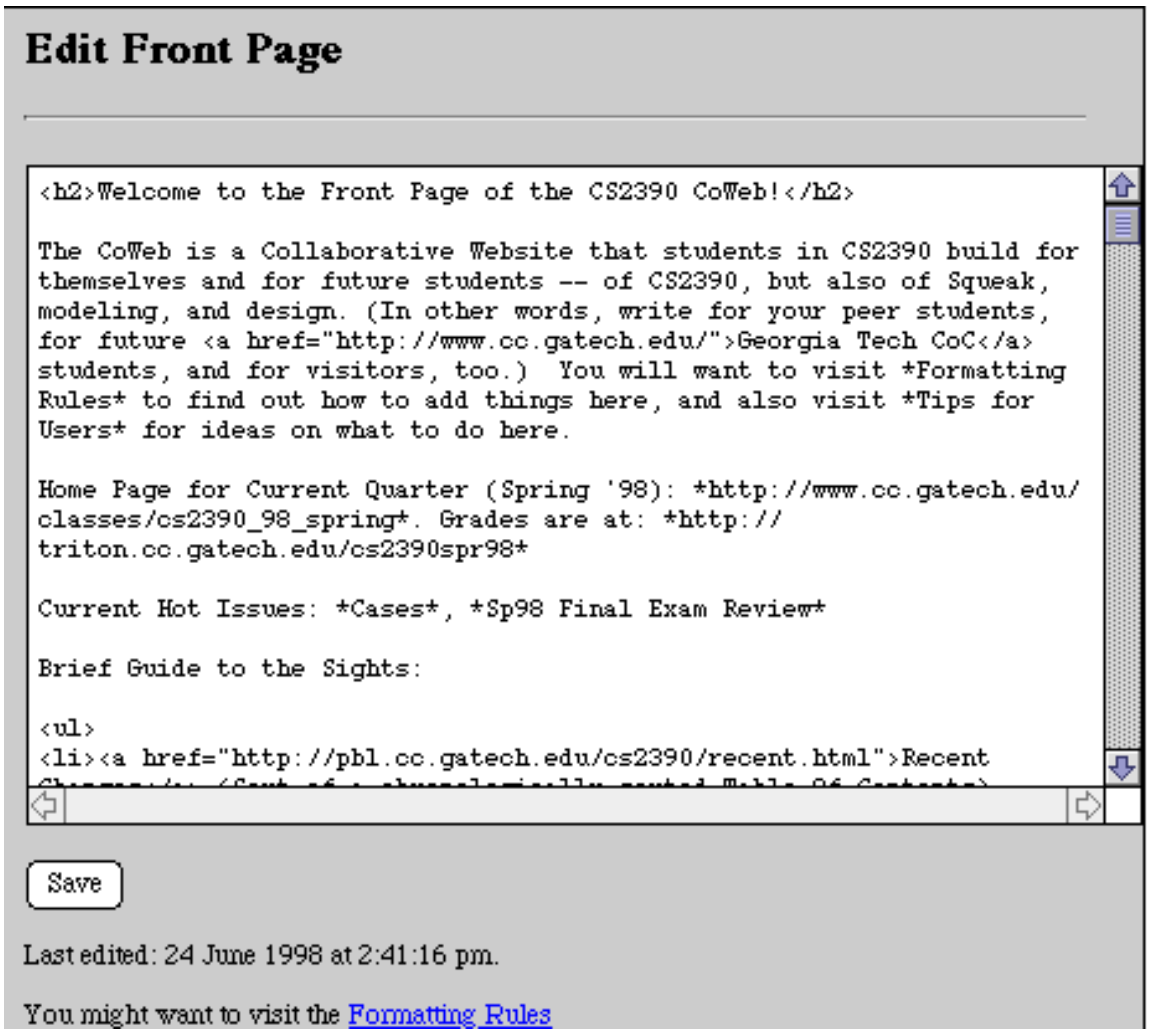

Figure 2: Editing the Page Seen in Figure 1

III. Uses of the CoWeb

The most interesting aspect of the CoWeb is the diverse purposes invented by the users. This section presents many of these purposes. The discussion is split into uses by teachers, students, and researchers because the expectations of audience, purpose, and background knowledge are different for each group. Teachers are typically creating materials for their own classes. Higher education teachers may have no training in

education at all, but their goals are often include effective learning for their students. Researchers may have some background in education and technology, and are typically designing for use in many classes. Students have their own individualistic goals, which probably include getting good grades, but may not have to do with learning.

A. Uses by Teachers

The early adopters of CoWeb were immensely imaginative in their uses for the CoWeb. While I was occasionally involved in discussions on how to use the CoWeb, the teachers (and their teaching assistants) made all of their own pages. The ideas were the teachers' own ideas, and the authoring of those ideas was entirely their own.

Information source. The first use for many faculty was simply a course website. The CoWeb lends itself to being a course website particularly for those faculty who are uncomfortable with traditional methods of managing a website (e.g., creating and editing files). But even faculty who are comfortable with technical concepts like HTML and FTP appreciated the CoWeb as an information source, as one CS professor noted when he wrote me, "I just love this CoWeb! I just like the interaction that it enables. It's basically just a whiteboard that everyone can write on. Protections are always kind of a pain."

There is the obvious problem that information could be changed on the CoWeb by someone not in authority. For example, a student might edit a teacher's announcement to have it say something different than what was intended. While we received no reports of malicious editing in the CoWeb, several faculty used two websites for their classes: A

traditional one with information whose authority needed to be assured (e.g., an assignment description), and a CoWeb for more informal news and information.

Student introductions. In many classes using the CoWeb, students were asked to create a "Who's Who" page for themselves, typically on a page named "Who's Who" and linked to the front page of the CoWeb. Students typically include links to their external home pages, and perhaps include a picture of themselves. The activity is useful for introducing students to the mechanics of the CoWeb. An additional benefit of the Who's Who activity is the creation of a standard signature mechanism. As I and other users of the CoWeb make postings, we can sign them with our name, e.g., *Mark Guzdial*. The signature, when saved, stands out as a link in most browsers, which serves to delimit our posting. Further, the signature becomes a link to our individual Who's Who pages, so readers can learn more about the posters with a single click.

Student assignment hand-in and review. Another common first use for the CoWeb was a "hand-in" site, where students would post their homework assignments when they were ready for grading. While perhaps not appropriate for every class, a public hand-in system provides the students an opportunity to see one another's work and even comment upon it—and provides the teacher the opportunity to orchestrate that kind of activity. In at least one class, serious and contentful class discussions developed out of students reading and posting comments about one another's essays being handed in via the CoWeb.

Collaborative Writing. In a human anatomy class, students were asked to do collaborative writing projects on the CoWeb. The teaching assistant created a page for

each topic that groups could choose from. On each of the pages, the assistant created four or five spaces for signing up for the given topic. Students in a group would edit the same page to enter their text for the group project.

The CoWeb is an interesting medium for educational collaborative writing because of the *inefficiencies* that it affords. In professional collaborative writing tools (such as in Microsoft Word), each participants edits or comments are clearly marked (e.g., with color) and are identified by participant. Professionals need not spend time reading over the entire document, but can instead focus on the new or changed material. On the CoWeb, pages are only identified as having been changed (on the "Recent Changes" page). For the student to find out what is new or changed on her group's collaborative writing page, she must actually *read* the page. A more common model of collaboration, at least in undergraduate engineering education, is the "staple-together model" (Newstetter & Hmelo, 1996). Students split up a collaborative task, solve each piece separately, then staple all the pieces together before turning it in for a grade. A CoWeb collaboration is in marked contrast to the "staple-together model" since students need to read one another's sections to determine what has changed, which may help them see how the whole arises from their individual pieces.

Anchored Discussion. One of common uses for collaboration spaces at Georgia Tech is *anchored discussion*. An anchored collaboration is a good structure to use for review activities (such as the design review listed above), but is also useful for supporting focused discussions. Common examples of an anchored discussion are students studying for a final exam by posting and critiquing answers to sample questions, or students asking

questions about an (anchor) assignment. Anchored collaboration was particularly simple to implement in the CoWeb, since the collaboration space can literally be the same space as the anchor.

Students did use the CoWeb for anchored, focused discussions. Students used a mechanism of writing their comments at the end of an anchor or comment page, usually signed. While there was no explicit support for tracking "threads" of comments (i.e., when one note comments upon another note, which comments upon another note (Guzdial, 1997)), a variety of mechanisms were invented by users (teacher or students) for marking threads. A common mechanism was the use of horizontal lines (generated in the CoWeb by simply typing '----' on a line) to mark separate threads, and a second was the students' spreading their discussion across several pages, so that each page served as the marker of a given thread.

An interesting artifact of the structure of the CoWeb is that discussions did not always progress linearly down the page. Particularly if the page contained source code for comment, student additions were often placed at the relevant point in the code. Sometimes notes were removed if they were no longer relevant. In a sense, the discussion itself was a collaborative artifact for modification and improvement.

Project case library. In some classes, students were invited to post their homework assignments *after* grading, particularly if the grade was high. The CoWeb became a project case library for exemplary projects (Guzdial & Kehoe, 1998). Students used these projects as examples of highly graded projects, as sources for ideas (particularly when two or more students posted their unique solutions to the same problem), and, in

programming classes, as sources for code that could be re-used in new projects. Frequently, students were offered extra credit as an incentive to post to the project case library. The amount of extra credit was often linked to the amount of extra effort that the teacher felt that the student had put into creating the case. Simply posting what had been handed in for a grade was not worth as much as also including a discussion of the flaws and strengths of the project, for example.

In a class that I taught in computer science, the project case library became a mechanism for communication across classes. I used the same CoWeb for successive terms of the same class. Students in the second term using the CoWeb reviewed the project cases from the first term and left notes on them. Students from the first term revisited the CoWeb during the second term, answering questions and sometimes changing and improving their cases. The CoWeb thus facilitated a kind of apprenticeship exchange, where more senior students came back to help younger students (Collins, Brown, & Newman, 1989).

As the project case library in my class grew larger (as of this writing, over 100 cases), some students began creating indices or recommendations of their favorite cases, also for extra credit. The students' (self selected) choices for indices were intriguing. One student identified the common characteristics of the first, second, and third assignments in my class, then identified the cases that best met those characteristics. Another student indexed the cases based on final grade, presumably because 100's would be the most valuable to other students.

Cross-Class Projects. In one application of the CoWeb, the involvement of junior and senior students was the explicit goal. Two classes in Chemical Engineering were paired using the CoWeb. The Senior level course had students designing a chemical system then constructing a simulation of the system. The Sophomore level course was on analyzing exactly that kind of simulation. Because of curriculum paths, it was possible for the Seniors never to have taken the Sophomore level course. The two Chemical Engineering faculty teaching the classes decided to require a cross-class project where Seniors would create the simulation, pass the data to the Sophomores who would analyze the simulation and return the results to the Seniors, who would use the results to complete the simulation. The CoWeb provided an open forum for sharing data, deciding on formats and other issues for such a technical collaboration, and working together on the solution.

Cross-Term Communication. Rather than start out with a blank space, CoWeb-using teachers teaching a class again (or teaching a related class) sometimes simply reused a past CoWeb. Since CoWeb pages cannot be deleted, the teacher would create new pages (e.g., "Old FrontPage"), copy references to the past content into the new page, then restructure the CoWeb for his new class. In one case, the same CoWeb was used for the first and second courses in human-computer interaction. In another example, a CoWeb was used for both the graduate and undergraduate versions of the same class (in that order, so that graduate level discussions and examples were available in the space to the more novice students). In my own class, I have used the same CoWeb for over a year, through four iterations of the same course.

The result is a sense of "termlessness" (Koschmann, In Press) to the CoWeb and to the content of the course itself. Student comments and server logging data indicate that students do visit the older content. Students see quite explicitly that the course domain extends beyond just this one course instantiation, and there are multiple ways to explore the domain. The older content serves as examples, even when not structured explicitly as cases. We hope to explore in later studies exactly what students might be gaining from collaborative spaces that break down the perception of classes being limited to a single term.

B. Uses by Students

Students' roles in the CoWeb varied with the teachers' choice and invention of activities. In some cases, the CoWeb was just an information source and perhaps a place to hand in homework. In other cases, the CoWeb was left as a completely blank space for the students to use as they wished. In still other cases, the students had assigned roles, but were welcome to engage in open-authoring as they wished. In any case, there was nothing in the CoWeb to *prevent* the students from creating any pages that they wished.

Students did create their own pages and features within the CoWeb in a variety of classes. The below list describes several of the interesting pages and features created by students.

Hot List. One of the most useful navigation features on my class CoWeb was a “Hot List” at the top of the CoWeb of pages which were particularly useful or on which there were active discussions. I did not invent the activity—I found the list on the FrontPage,

as did other students. The Hot List is a feature that I now maintain, but often with student contributions. If a student creates a page that she wishes others to find and comment upon, she will often place it in the Hot List for some time.

Student-Created Anchored Discussions: Students used the CoWeb to create special interest pages that invite contributions from others. For example, if a homework assignment or exam is particularly intriguing (or aggravating!), students will sometimes create a page for discussion of the assignment or exam. If a student feels strongly about an issue, it is not uncommon for him to create a page for discussing this issue. Examples that have occurred in some of CoWebs at Georgia Tech include extending a discussion from class lecture ("I did not get a chance in class to explain my points…") and complaining about a theme in the class or in the assignments ("The assignments in this class all have a serious design flaw…"). Other students are explicitly invited on these pages to engage in a discussion, and many do.

Not all the student-created anchored discussions were so focused on class learning objectives. Some dealt with some of students' other goals. Our CoWeb also hosted the College list of players of the network game “TeamFortress,” which appeared in the first few weeks of the first term using the CoWeb. One TeamFortress player in the class created the page, with a formatted table listing key player information like the player’s “clan.” Other students then filled in their information in the table. Six months later, the "Quake2" signup page showed up on the class CoWeb.

Choose-Your-Path Adventure Game. In one class CoWeb, students created an adventure game about one of their assignments, like a “Choose Your Path” book. A

student created a situation (based on the simulation assignment that they were working on, started two nights before the assignment was due) with a set of links representing choices that the reader might select from. Other students added to the set of choices and created a variety of pages in the adventure game. Almost three dozen pages were created in this adventure.

Student Information Pages. Sometimes the CoWeb is just used by students as a place to post information for others, relevant to the class or not. CoWeb pages make good places to create collaborative hot lists, and students will frequently contribute links to material that they think others will find valuable. In at least two class CoWebs, students posted songs that they invented about the class.

C. Uses by Researchers

The CoWeb is also proving to be a useful platform for exploring collaborative issues where a special-purpose space might be too complicated or expensive to develop. The CoWeb provides a means for easily exploring the *what* (will people do with the space) before exploring the *how* (do we build a space for this kind of purpose) questions. In several of these cases, modified forms of the CoWeb were created in order to provide specific capabilities, but without modifying the basic open-authoring nature of the CoWeb. I am involved with each of the below projects, with different collaborators in each case. The projects described in this section present some intriguing possibilities for open authoring.

Professional and Peer Design Review. In an architecture class, students were asked to create two CoWeb pages for each of their projects, in a space called CoOL Studio (Collaborative On-Line design Studio). CoOL Studio was designed and developed with Architecture colleagues David Craig, Saif-ul Haq, Sabir Kahn, and Craig Zimring. On one page, students were asked to post descriptions of their projects ("pin-ups") with scanned images of their drawings. On another page, students were asked to identify research questions that they needed to answer in order to complete their designs, such as the optimal size of hallways for a given kind of building and kind of use. The goal of this structure was to provide students with an opportunity to review each others' projects and to help one another in answering their research questions.

On two occasions during the class, expert architects were invited to tour the students' pin-ups and comment on the projects. For each expert architect, a "tour page" was set up with the architect's name on it. The architect was invited to visit each of the pin-up pages listed on his or her tour, and comment on the pin-ups either directly on the student's page or on the tour page. This activity was judged to be fairly successful. The experts wrote a surprising amount of commentary. They wrote sometimes left comments on students' pin-up pages with particular advice, and sometimes they wrote on the tour page with general advice that the expert felt that the whole class group needed. Students took the reviews quite seriously, and the experts reported enjoying the experience (Zimring, Khan, Craig, Haq, & Guzdial, 1999). Experts particularly enjoyed reading one another's postings and seeing how their peers responded to the students' work.

The CoWeb played an enabling role in the activity. The expert architects could contribute from a distance, on their own time, and with little new learning required, since most already knew how to use browsers. Students could tell from the "Recent Changes" page when someone had edited their page or a tour page that their work was on. The CoWeb served to enable a valuable kind of interaction which might not have happened otherwise. Having experts respond to students' work and questions is a tele-mentoring activity which has great value, but is often difficult to actually implement (Bruckman, 1997). The CoWeb provided a forum for students to describe their work, and for experts to review and comment on the work, with no special technology or programming.

However, there were definite limitations to use of the CoWeb in CoOL Studio. For example, the architecture students, who were quite familiar with creating project pin-ups in physical spaces, were quite unfamiliar with how to lay out materials on a Web page. On the other hand. The faculty involved thought that even this limitation may have had its benefit, by requiring the students to reflect on their designs in order to determine the most critical aspects and how best to convey those aspects

Most striking has been the impact of CoOL Studio on the Architecture community. The CoOL Studio project was awarded a 1999 Design Research Award from *Architecture Magazine*, and the American Institute of Architecture Education Honors Awards Competition made CoOL Studio one of its two 1999 award recipients. While there are excellent examples of advanced technology being used in Architecture to support design studio activity, e.g., (Wojtowicz, 1995), the learning activities in CoOL Studio were

supported with very minimal technology, and yet allowed discussion between diverse groups of students and expert architects.

Collaborative Radio Station: An unusual CoWeb is being used to explore the concept of a collaborative radio station, where listener/users create their own radio programs and even collaborate on define radio programs. The collaborative radio station is being used to explore two different research agendas. The first is on the power of a collaborative radio station to influence the sense of community in the audience. The second is on how we might provide an audience to student-generated compositions in a special math-for-music project.

A variation on the CoWeb was created which allows for users to upload files onto the server through the CoWeb. The *JukeBox CoWeb* was used to define radio programs and to hold uploaded sound (WAV and AIFF) and music (MIDI) files. Radio programs were created by simply creating a page off a pre-defined *Schedule* page, then listing the names of the files to play in order. Listeners could tune into the radio in two ways.

- The server computer (a PowerMac 7600) ran a process to play each of the files on each of programs in their order on the Schedule page. The audio output of the computer was played through an inexpensive radio transmitter. The range of the transmitter was limited, however, and was only available in part of the building in which it was housed.
- A listener program was created that would allow the user to play the whole schedule or just a favorite program on their own computer. Files were fetched from the server in the background and then played via the audio capabilities of

the user's computer.

While technically interesting, the collaborative radio was less successful than we hoped. In an ethnographic study of users of the collaborative radio (Walker & Guzdial, Submitted), we found that users will reluctant to be either DJ's or listeners for long. Few casual users had a lot of pre-recorded material in the appropriate formats. Listening quality was limited by distance to the transmitter, the quality of the audio on the listener's computer, and the relatively spare MIDI format.

Extending Captured Lectures. Classroom 2000 is a research effort at Georgia Tech to explore the capture of multiple streams of data in a classroom, including audio, video, and lecturer's slides and notes (Abowd et al., 1998). Playback of the Classroom 2000 captured lecture occurs on the Web, where students can review the slides of the lecture and play back the audio and video from any point in the lecture. We connected the Classroom 2000 playback capability to the CoWeb in order to provide a space for continuing lecture discussions after class.

The user of Classroom 2000 had prompts after each slide for the name of a page to be linked to the given slide. The CoWeb server was modified to accept this name and to return a URL to the appropriate page (creating it, if it did not already exist). Classroom 2000 software then presented the page name as a link to the CoWeb page from that slide, and the CoWeb page was appended with a thumbnail of the slide and a link to the page.

The use of the Classroom 2000 and CoWeb combination was somewhat surprising. Students used the CoWeb more often than they visited the captured lectures. Rather than using the CoWeb as a discussion space for the lectures, students used the lectures as a

medium for expanding upon their discussion in the CoWeb (Abowd, Pimentel, Kerimbaev, Ishiguro, & Guzdial, Submitted).

IV. Student Attitudes toward the CoWeb and Open Authoring

A survey of student attitudes and experiences was developed and distributed to three classes during the Winter 1998 quarter at Georgia Tech[5].

- A 40+ person Biology class that used the CoWeb for collaborative writing. 38 students completed the survey
- A 15 person Chemical Engineering class that used the CoWeb to coordinate cross-class collaboration. Three students completed the survey.
- A 100+ Computer Science class that used the CoWeb for a variety of activities including building a case library, reviewing for exams through an anchored collaboration structure, and discussing programming assignments. 52 students completed the survey.

Students were asked to respond to the following questions on a five point scale, where 1 is Strongly Agree and 5 is Strongly Disagree. (Values in parentheses are standard deviations.)

Statement	Bio	CS	ChemE
The CoWeb was useful	2.1 (0.6)	1.7 (0.8)	2 (1.7)

[5] The data presented in this section was originally discussed in (Guzdial, 1999) and appears (in part) in (Guzdial et al., Submitted).

The CoWeb is easier to use than email for sharing information with the class.	2.4 (1.0)	1.8 (1.0)	1.7 (0.6)
The CoWeb is easier to use than newsgroups for sharing information with the class	2.2 (0.9)	2.4 (1.3)	1.7 (0.6)
I liked using the CoWeb	2.2 (0.7)	1.9 (1.0)	1.3 (0.6)
The CoWeb frustrated me.	3.6 (1.0)	4.0 (1.0)	4
I have my own page (or pages) in the CoWeb	2.5 (1.1)	3.1 (1.8)	4
I was motivated to maintain my own page (or pages) in the CoWeb	3.0 (1.0)	3.6 (1.1)	3.3 (0.7)
My main reason for using the CoWeb was to get information from my teacher.	3.1 (1.0)	2.5 (1.1)	1.7 (0.6)
The CoWeb helped me to perform class assignments.	1.8 (0.8)	1.7 (1.0)	2
The CoWeb helped me to learn.	2.8 (0.7)	1.8 (1.0)	2 (1.7)
I learned more from other students in the CoWeb than the teacher in the CoWeb.	3.4 (0.8)	3.0 (1.0)	5
I would like to use the CoWeb in other classes	2.5 (0.9)	2.1 (1.2)	3.3 (1.1)
Reading and updating the CoWeb was a chore.	3.1 (0.9)	3.4 (1.1)	4
I will come back to visit this CoWeb after this class ends.	3.6 (0.9)	3.0 (1.3)	4

We also split some data between those that reported that they had created CoWeb pages (49 students) and those that hadn't (44) in order explore the change in perspective between those who actively authored and those who did not.

Statement	**Create**	**No-Create**
I liked using the CoWeb	2.0 (0.9)	2.1 (0.9)
The CoWeb frustrated me.	3.9 (1.1)	3.8 (0.9)
I have my own page (or pages) in the CoWeb	2.3 (1.4)	3.6 (1.4)
I was motivated to maintain my own page (or pages) in the CoWeb	3.1 (1.1)	3.5 (1.0)
The CoWeb helped me to learn.	2.4 (1.0)	2.1 (1.0)
I learned more from other students in the CoWeb than the teacher in the CoWeb.	3.3 (1.0)	3.2 (1.0)
Reading and updating the CoWeb was a chore.	3.2 (1.0)	3.4 (1.0)
I will come back to visit this CoWeb after this class ends.	3.1 (1.2)	3.5 (1.1)

A. Discussion of Survey Results

This is a preliminary survey, and not even particularly well-designed. For example, there is often only one statement for each concept, rather than several statements to serve to verify or triangulate around a concept. However, there are some very interesting trends in these data that are worth exploring in future studies.

It is clear that, in general, students liked the CoWeb. Students found it useful, they liked it, they want to use it in other classes, they weren't frustrated by it, and they didn't find reading and writing a chore. (Biology students were almost ambivalent about whether reading and writing was a chore.) In general, they found it easier to share things with a class than email or newsgroups. Students also (on average) found that the CoWeb helped in class task performance and in learning.

The beginning of a shift from a teacher-centered culture can be seen in these data. There was a strong indication that the teacher's involvement was important (i.e., students agreed with the statement "My main reason for using the CoWeb was to get information from my teacher") to the Computer Science and Chemical Engineering students, though the Biology students actually slightly disagreed with the statement on average. Most surprising was that the Computer Science students are ambivalent (on average), and Biology students nearly so, about the statement that "I learned more from other students in the CoWeb than the teacher in the CoWeb." That's quite a shift in attitude from a lecture-based perspective where the teacher is the main source of information, to one where the teacher is valued, but others are valued too. Chemical Engineering students, however, strongly disagreed that they learned more from other students than from the teacher in the CoWeb. This result may indicate a more conservative attitude in Engineering, or perhaps is not representative since only three students responded.

Students who created CoWeb pages seemed to agree that they "had their own page" in the CoWeb. That sense of ownership is interesting, because it can help to explain the students' motivation in creating the collaborative activities we see them engaging in.

However, it's not clear what that "own pages" means. Students who created their own pages were more likely to claim that they would return to visit the site after, which suggests that some of them did in fact plan to revisit their page, as we had observed. We see that as an interesting and unusual cultural shift toward a more apprenticeship model of education, where senior students visit with and help younger students.

V. Making the CoWeb Successful in Classes

Not all CoWeb instances were successful in all classes, as judged by the opinion of the teachers and the students. Sometimes very little discussion ensued. Sometimes students did not visit the page at all. In the two years of use of the CoWeb, we have learned some heuristics for what makes for a successful CoWeb, where students and teachers feel that the space is dynamic and valuable.

Structure of a Class CoWeb

The least successful CoWebs are the ones where the teacher asks a CoWeb to be created for her class, announces it to the students on the first day of class, and never touches it. Part of the problem in this model is the lack of participation of the teacher, which is discussed later in this section. But part of the problem, too, is the lack of appropriate structure in the CoWeb.

We have found that students are surprising reticent to edit or create CoWeb pages, at least at the beginning of the class. Even in a successful use, there is rarely much activity in the first weeks of the class. Students must be explicitly invited to participate in the CoWeb.

An effective way of making the invitation is by creating a collection of pages on the Front Page of the CoWeb which invite different kinds of activity. Each of the discussion pages contains some text explaining what is appropriate on the given page. Some example pages include:

- *Who's Who* where students introduce themselves
- *Cases* where cases are posted
- *Comments* where comments are solicited. (Often, the Comments page contains references to several other pages where more specific comments are solicited, e.g., on Homework Project #1, or on the topic of the first paper.)
- *Tips and Resources* where students leave pointers to useful information on the Web
- *Sandbox,* an "Experiment Area" where students were encouraged to explore use of the CoWeb.

Having a half dozen places where focused activity is encouraged tends to be more successful than a nearly blank Front Page that invites any kind of activity. While in some classes students may be motivated enough to make a blank Front Page work, in most cases, we have found that more specific invitation is valuable.

Structuring Class Activities

Once the CoWeb is set up, students need a reason to go visit the site, and to recognize its usefulness. We have found that the most successful CoWebs tend to have two kinds of activities early on in the class.

- First, there is a required or strongly encouraged simple activity for everyone to learn the mechanics of creating pages. In some classes, students were explicitly requested to create a CoWeb page for themselves on the Who's Who page. In other classes, the students were asked to create a page for an initial homework essay or for their class journal entries.
- Early in the class, there is some organized activity that involved students editing CoWeb pages and engaging in a discussion. The goal is to have an activity that is valuable to engage in, but is not required. In one class, it was a discussion of a report available on a Web page. In another, it was a midterm examination review where students were invited to post answers or comment on others' answers to a sample exam. This second activity served to bootstrap discussion and to model the kind of activity which could be organized in the CoWeb.

A technical issue in creating CoWeb activities is to not set up a bottleneck for students. If all students haveto post to a single CoWeb page as part of a required assignment, then that page becomes a bottleneck. When the majority of students attempt to complete the assignment near the deadline, students are racing for a scarce resource. Frustrated students tend not to participate freely in open authoring activities.

Connecting Evaluation and CoWeb Activities

In relatively few classes have students been evaluated on the quality of their postings in the CoWeb. We feel that evaluating students based on their discussion is a hindrance to

an open authoring environment. The threat of evaluation tends to close down some kinds of discussion.

Nevertheless, many students do seem to need to feel that activity in the CoWeb will help their grade, as a way of justifying the activity as being worthwhile. The tie between evaluation and use of the CoWeb is important. We have found two ways of making this tie.

The first is explicit: Students receive extra credit in the class for posting cases. As mentioned, these cases can be based on coursework. However, we have also seen effective cases based on student investigations into relevant domain literature, or even student-invented projects of similar complexity to coursework.

The second is a by-product of the first and provides a more implicit connection to evaluation: The CoWeb must have discussions and content that can help in achieving better grades. In a project-based class, the written assignment statement rarely answers all the students' questions about what needs to be done. In engineering and science higher-education, much of the coursework revolves around student projects. By providing spaces for discussing projects, the teacher creates a reason for using the CoWeb so that engaging in the discussion can lead to a better understanding of the assignment and perhaps a better grade. Cases, past discussions, and other content that directly relate to the project also serve to enhance the value of the CoWeb to the students through their bottom line—their grade.

Role of the Teacher

We know that the teacher's participation is key to success in other computer-supported collaborative learning situations (Guzdial, 1997; Guzdial & Turns, 1999), and the survey results presented earlier suggest that teacher participation is important on the CoWeb, too. The value of the teacher's participation is not just in the content that they provide, however. The teacher also has important roles in establishing value for the space and in mediating the conversation.

The teacher's frequent participation in the CoWeb indicates that the teacher thinks that the CoWeb is valuable. In some activities (like a midterm exam review or discussion of a project assignment), the teacher's non-participation can detract from the value of the activity. But in other activities, the teacher can provide value without participation.

In a graduate CS class, the teacher successfully used an unusual strategy for creating value for the CoWeb in her class. She was fairly active in the CoWeb during the first two weeks of the course, so that her "signature" link to her Who's Who page appeared frequently in the CoWeb's pages. But after the first two weeks, she found it difficult to visit the space often. However, in class, she made frequent references to the CoWeb, with comments like "That's a great point. Could you please add that to the CoWeb?" and "I don't know where to find that either, but could you find it and then put a link in the CoWeb?" Through this combination, the teacher kept a high-profile for the CoWeb and made clear that she found it valuable, even if she could not participate frequently.

The role of the teacher in mediating the conversation is a challenging balancing act. On the one hand, the teacher wants to provide information. But on the other hand, too much

information kills the discussion. Even in an open authoring environment, the role of the teacher is privileged and has enormous sway over the participants. I discovered this in my own class during exam review sessions. I discovered that the worst thing that I could write on a students' potential solution was "That's right!" because, once the solution was identified, all discussion and potential solutions were moot. I found I could maintain more conversation by remarking, "That's a good answer, but there are other acceptable alternatives too," and even judiciously choosing not to respond to a particularly good solution. By not answering, I opened the door for other students who would occasionally question the solution, leading to an effective and on-topic discussion.

IV. Conclusions: Characterizing Uses of the CoWeb

In the previous sections, I have introduced the CoWeb and some of its uses as an open-authoring environment. Section IV contains a discussion of a recent survey of CoWeb-using students' attitudes, which is promising in that it indicates student perceptions of value for peer collaboration in learning and a value for self-authored pages. Section V presents some of the lessons learned from two years of establishing the CoWeb in classes.

This paper, however, does not present an argument that learning is actually occurring and is being facilitated in classes using the CoWeb. Rather, the CoWeb story is about what teachers, students, and researchers will do with an open authoring environment. The question of learning effectiveness is better asked about the individual activities than the CoWeb itself. What is intriguing is the range and diversity of activities being invented for

the CoWeb. The goal of this paper is not to show that the CoWeb is educationally effective, but that the open authoring made possible by the CoWeb facilitates a set of activities that hold promise for learning.

The promise that the CoWeb holds is the promise of *constructionism.* Constructionism is the approach to learning that says that learning occurs best through creation of a public artifact (Papert, 1991). The goal of the uses of the CoWeb described above are mostly about learning. The artifact that is produced through use of the CoWeb (that is, the website itself) is an important, public part of the process. But even when the applications of the CoWeb have not been explicitly about learning (e.g., the signup sheet for TeamFortress, or the collaborative radio), the activity facilitates the student in recognizing in themselves the role of contributor and author. Regardless of whether the teacher using the CoWeb explicitly seeks to create a constructionist activity, or even believes in constructionism, the use of the CoWeb creates an opportunity for open authoring in which the artifact created is public. If the context for the CoWeb is a class, and thus has the explicit goal to learn, the elements are there to enable a constructionist form of learning. Future research can explore whether that learning does occur, what is learned, whether the whole class learns, whether the teacher's attitudes toward learning change, and how dynamic, transferable, and retainable the students' learning is.

The CoWeb is not a panacea for collaborative activities. For example, it is not optimized for productive collaborative writing. There are many tools available to commercial users that are much more optimized for collaborative writing than the CoWeb, such as Microsoft Word and Lotus Notes. The CoWeb is optimized to encourage users to

read whole pages of material and to contribute (by editing text, by creating pages, etc.) anywhere. The approach in the CoWeb emphasizes individuals getting involved in the writing and reading a good deal, but it is inefficient.

The CoWeb is not the best tool for all computer-supported collaborative learning situations (as described further in the next section). It may be well-suited to the diverse nature of higher-education. However, it's most important role has been to help us see what users will invent for learning contexts with the CoWeb when the design of the collaborative space is in their hands and not in the hands of the designers.

A. CoWeb Tradeoffs

The CoWeb is only one of several Web-based collaboration tools that have been created for learners. It is worthwhile looking at the tradeoffs that were chosen between others and the CoWeb, and to see how those tradeoffs impact the kinds of applications that can be authored with these tools. In general, the CoWeb does not structure the process of collaborating as other tools do, which makes it desirable in some settings (e.g., with adult learners) and less desirable in others.

CoNote (Davis & Huttenlocher, 1995), SpeakEasy/MFK (Hsi & Hoadley, 1994; Hsi & Hoadley, 1997), and CaMILE (Guzdial et al., 1997; Guzdial et al., 1996; Guzdial, Turns, Rappin, & Carlson, 1995) have all been used successfully in education contexts. CoNote is a system through which students make annotations to existing Web pages. SpeakEasy/MFK and CaMILE are both threaded discussion spaces. SpeakEasy/MFK is a multi-representation tool where students are asked to make a statement about a

discussion question, and then engage in a facilitated discussion about the question. CaMILE only offers facilitated threaded discussions, but it supports anchored collaboration so that threads of discussion can be accessed from any page on the Web. Both SpeakEasy/MFK and CaMILE offer a form of discussion facilitation where users are prompted to identify the kind of note that they are posting, as a way of encouraging reflection about the collaboration process.

These other collaboration spaces are perhaps better suited where the users need a more focused and more constrained activity, such as elementary school or middle school students. All three of these tools provide more support than the CoWeb. Students do not need to know anything about URL's, page editing vs. page viewing, or HTML. Usage in these other tools is more controlled. Users of CoNote, SpeakEasy/MFK, and CaMILE have to sign in, so that their identity is known and each user's contribution can be tracked. Users cannot delete or modify other users' postings. The CoWeb offers none of these benefits: It is more complicated to use, individual contributions cannot be identified with confidence, and it is possible for one user to modify or delete another user's posting.

On the other hand, the CoWeb has a higher "ceiling" than threaded discussion spaces. It is not possible in these spaces to have persistent, user-created pages for marketing a toolkit and discussing it, nor is it possible for students to invent the activity of a collaborative adventure game. The CoWeb provides more flexibility in authoring activities, but at several costs that it more suited to the more mature learner.

B. Dynamic Scaffolding

The CoWeb, in general, supports *dynamic scaffolding*. Scaffolding, as previously mentioned, is a kind of support that is provided to students to enable them to succeed at a process, where they might not succeed without the support. It is characterized as the kind of support that a master or senior student might provide to younger students in an apprenticeship relationship (Collins et al., 1989). Dynamic scaffolding[6] describes scaffolding that crosses borders (i.e., scaffolding provided in the classroom, scaffolding provided via software, scaffolding provided while students work) and changes over time in order to support different kinds of processes that students are engaging in. When students are invited to author pages and create applications, dynamic scaffolding does not all extend from the teacher. The students can be teachers, providing scaffolding for themselves and their peers, and the teacher can even be a participant in the students' activities.

Dynamic scaffolding is so named to contrast it with other kinds of scaffolding that is pre-defined with particular prompts and structures (e.g., (Guzdial, 1995; Soloway et al., 1996a)). Software-realized scaffolding, scaffolding provided through paper forms, or other forms of scaffolding can be highly effective. Dynamic scaffolding may even be less effective than these others, given that it arises dynamically in response to the situation. However, open authoring does facilitate open authoring in a unique way.

---

[6] The term "dynamic scaffolding" was coined by Janet Kolodner to describe some of what she saw going on in the CoWeb.

A real example of using the CoWeb for dynamic scaffolding can help to make the issue more concrete. This example is drawn from a computer science class that I taught. I assigned four homework projects, due at intervals across the term, but announced all on the first day. In all four projects, students were asked to create some kind of user interface.

- In lecture at the beginning of the term, I encouraged students to construct tools to make their job easier through use of user interface toolkits. During the first few weeks, I lectured on features of a good user interface toolkit and how those features could be created.
- As part of the class evaluation, I offered extra credit to students who made their toolkits available to others when other students credited the toolkits in their homework.
- The CoWeb served several functions in this activity. I created a page for advertising students' user interface toolkits. As students developed a toolkit, they would create a new page (or multiple pages) and reference the toolkit page(s) from the main advertising page. Five toolkits were eventually created (by three to four person teams, out of a class of just over 100 students) and posted to the CoWeb. On the students' toolkit pages, they documented their toolkits (e.g., provided sample code, described how the toolkit worked) and blatantly marketed their toolkit as preferable to other available toolkits. These pages were used by customer students (including myself, as I was trying some of the student contributions) for asking questions about the toolkits.

- Later in lecture, we discussed the strengths and weaknesses of the individual toolkits and provided opportunity for various students (both toolkit developers and consumers) to demonstrate their programs.
- In later offerings of the class, other students have continued to use these toolkits and to produce new toolkits to add to the list and the discussion on the CoWeb.

The example shows an activity crossing boundaries between classroom activity and students' homework activity (in lab and dorm room), between software and face-to-face interaction, between lecture, discussion, and virtual discussion space. Students played multiple roles in this activity: Developers, consumers, marketers, technical support, and even teachers. The CoWeb enabled this structure. It served different roles at different times: As *advertising* early on when consumer students were considering their options, as *documentation* when students were using a toolkit, and as a *communications* medium when students needed help. The open authoring character of the CoWeb enabled this diversity of use.

The example activity set up the opportunity for several benefits for students. Those students who created toolkits had the experience of creating a software product with users. Those students who consumed toolkits had the experience of shopping for a software product that they would develop with and having to choose between several. Perhaps the most important benefit, however, was the explicit encouragement to students to create a higher level of agency for themselves and take charge of their scaffolding.

C. Open Authoring in Classes

Open authoring enables a new kind of role for students. Students were able to use the CoWeb to author their own pages and even their own collaborative activities, without teacher solicitation. That they would even *want* to write songs and adventure games about their class is really quite striking. It stands in sharp contrast to most depictions of engineering education culture, which is strongly grade-oriented and involves highly optimized, intensive work (Newstetter, 1997; Newstetter & Hmelo, 1996; Turns, Guzdial, Mistree, Allen, & Rosen, 1995)

Calling what users of the CoWeb did as "authoring" is different than what many have meant by that term, e.g., (Myers, 1998). Users of the CoWeb are not doing any programming nor any "scripting" (Ousterhout, 1997). Yet, teachers and students are creating interactive, collaborative applications. The teachers who created the collaborative writing CoWeb or the architectural design review CoWeb, and the students who created the TeamFortress sign-up page or the collaborative adventure game, were all creating structures for interactive use by others as part of a collaborative activity.

Open authoring may depend on the kind of protection that the CoWeb provides: more social than technical. The CoWebs at Georgia Tech have been amazingly free of malicious damage. Occasionally, inappropriate words or links to inappropriate sites do pop-up. They are quickly removed by *any* user of the CoWeb, not just the teacher. When no one has the role of police, everyone can take on that role.

Though some versions of the CoWeb do support password protection, open authoring may be hindered by its use. Users might feel inhibited from creating pages

freely as they do in an open CoWeb if user identification mechanisms, passwords, and permission mechanisms to be placed in the way. Certainly, the sense that users will find a collaborative page freely and be able to add to it would be diminished if some users were permitted to read and write while others were not. For example, my class CoWeb gets visitors both from past students and also from members the computer science education community who watch what's happening and even occasionally answer student notes. Free flow of participants is an advantage of the CoWeb and open authoring that password-protected pages may inhibit.

The technological mechanisms that the CoWeb inherited from Ward Cunningham's Wiki were critically important to the success of open authoring in the CoWeb. Without an easy way to find out what has changed (Recent Changes) and to find older items (searching), users would not have been able to find new places to collaborate and build upon one another's work so easily. These facilities in the context of the "any page is editable by anyone" philosophy create for a powerful authoring environment, where people can create pages that invite others to join in on the authoring and pages that build upon the work of others. In an education context, this is a powerful dynamic that empowers both students and teachers.

Acknowledgements

I owe many people thanks for their efforts in creating the CoWeb, its application, and our growing understanding of it. The CoWeb would not have happened without the pioneering work of Ward Cunningham. The CoWeb is built upon my Pluggable

WebServer , which built upon the work of Georg Gollman. All of the work in Squeak owes thanks to the Squeak team: Alan Kay, Dan Ingalls, John Maloney, Ted Kaehler, Scott Wallace, Andreas Raab, and Kim Rose. The CoWeb has been dramatically improved by the work of Ted Kaehler, with major contributions by Lex Spoon, Bijan Parsia, Bolot Kerimbaev, Jochen Rick, and Ross Philipson, among others. Matt Sanders did the first study of use of the CoWeb. The term CoWeb is due to Ben Hall. Bolot Kerimbaev invented the upload version of the CoWeb. The first study of the JukeBox CoWeb was by Rodney Walker. Aibek Musaev built the Jukebox listening program. Janet Kolodner and Jennifer Turns have helped me in understanding what has been happening in the CoWebs, as well as Amy Bruckman, Noel Rappin, Colleen Kehoe, and Nora Sabelli. I owe a great deal of thanks to the students, teachers, and external users who have used the CoWeb and helped me understand their use including, Beth Mynatt, Mindy Millard-Stafford, Ben Hall, Matthew Realff, Pete Ludovice, Janet Kolodner, Mike McCracken, Sabir Kahn, Craig Zimring, Saif-ul Haq, Greg Turk, Bijan Parsia, and Andreas Raab. Bijan Parsia, Ted Kaehler, and Jennifer Turns helped me in tuning and improving this paper. Funding for portions of this work has come from National Science Foundation grants RED-955045 and REC-9814770.

References

Abowd, G., Atkeson, C. G., Brotherton, J. A., Enqvist, T., Gully, P. A., & Lemon, J. (1998). Investigating the capture, integration, and access problem of ubiquitous computing in an educational setting, *Proceedings of CHI'98* . New York: ACM.

Abowd, G., Pimentel, M. d. G., Kerimbaev, B., Ishiguro, Y., & Guzdial, M. (Submitted). Anchoring discussions in lecture: An approach to collaboratively extending classroom digital media, *Proceedings of CSCL'99* . Palo Alto, CA.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist, 26*(3 & 4), 369-398.

Bruckman, A. (1997). The Design of Thoughtful Virtual Communities : Talk presented at Georgia Tech's College of Computing.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: Teaching the craft of reading, writing, and mathematics. In L. B. Resnick (Ed.), *Knowing, Learning, and Instruction: Essays in Honor of Robert Glaser* (pp. 453-494). Hillsdale, NJ: Lawrence Erlbaum and Associates.

Cunningham, W. (1998). What gets protected in a (S)Wiki : http://pbl.cc.gatech.edu:8080/myswiki.7.

Davis, J. R., & Huttenlocher, D. P. (1995). Shared Annotation for Cooperative Learning. In J. L. Schnase & E. L. Cunnius (Eds.), *CSCL'95 Proceedings* (pp. 84-88). Bloomington, IN: Lawrence Erlbaum and Associates.

Guzdial, M. (1995). Software-realized scaffolding to facilitate programming for science learning. *Interactive Learning Environments, 4*(1), 1-44.

Guzdial, M. (1997). Information ecology of collaborations in educational settings: Influence of tool. In R. Hall, N. Miyake, & N. Enyedy (Eds.), *Proceedings of Computer-Supported Collaborative Learning'97* (pp. 83-90). Toronto, Ontario, Canada.

Guzdial, M. (1999). Teacher and Student Authoring on the Web for Shifting Agency : Presented at the Annual Meeting of the American Educational Research Association as part of the session *How can CSCL (Computer Supported Collaborative Learning) change classroom culture and patterns of interaction among participants?*

Guzdial, M., Hmelo, C., Hübscher, R., Nagel, K., Newstetter, W., Puntembakar, S., Shabo, A., Turns, J., & Kolodner, J. L. (1997). Integrating and Guiding Collaboration: Lessons learned in computer-supported collaboration learning research at Georgia Tech. In R. Hall, N. Miyake, & N. Enyedy (Eds.), *Proceedings of Computer-Supported Collaborative Learning'97* (pp. 91-100). Toronto, Ontario, CANADA.

Guzdial, M., & Kehoe, C. (1998). Apprenticeship-based learning environments: A principled approach to providing software-realized scaffolding through hypermedia. *Journal of Interactive Learning Research, 9*(3/4).

Guzdial, M., Kolodner, J. L., Hmelo, C., Narayanan, H., Carlson, D., Rappin, N., Hübscher, R., Turns, J., & Newstetter, W. (1996). Computer support for learning through complex problem-solving. *Communications of the ACM, 39*(4), 43-45.

Guzdial, M., Realff, M., Ludovice, P., Morley, T., Kerce, C., Lyons, E., & Sukel, K. (Submitted). Using a CSCL-driven shft in agency to undertake educational reform, *Proceedings of CSCL'99* . Palo Alto, CA.

Guzdial, M., & Turns, J. (1999). Supporting sustained discussion through a computer-mediated anchored discussion forum. *Journal of the Learning Sciences*(Submitted).

Guzdial, M., Turns, J., Rappin, N., & Carlson, D. (1995). Collaborative support for learning in complex domains. In J. L. Schnase & E. L. Cunnius (Eds.), *Computer Support for Collaborative Learning (CSCL '95)* (pp. 157-160). Bloomington, IN: Lawrence Erlbaum Associates.

Hsi, S., & Hoadley, C. M. (1994). An interactive multimedia kiosk as a tool for collaborative discourse, reflection, and assessment : Draft.

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.

Ingalls, D., Kaehler, T., Maloney, J., Wallace, S., & Kay, A. (1997). Back to the Future: The Story of Squeak, A Practical Smalltalk Written in Itself, *OOPSLA'97 Conference Proceedings* (pp. 318-326). Atlanta, GA: ACM.

Jeong, H., & Chi, M. T. H. (1997). Construction of shared knowledge during collaborative learning. In R. Hall, N. Miyake, & N. Enyedy (Eds.), *Proceedings of Computer-Supported Collaborative Learning'97* (pp. 124-128). Toronto, Ontario, Canada.

Koschmann, T. (In Press). Tools of termlessness. In T. O'Shea (Ed.), *Virtual learning environments* .

Krajcik, J. S., Blumenfeld, P. C., Marx, R. W., & Soloway, E. (1994). A collaborative model for helping teachers learn project-based instruction. *Elementary School Journal, 94*(5), 483-497.

Myers, B. A. (1998). *Natural Programming: Project overview and proposal* (Technical Report CMU-CS-98-101/CMU-HCII-98-100): HCI Institute, School of Computer Science, Carnegie Mellon University.

Newstetter, W. C. (1997). Of green monkeys and failed affordances. *Anthropology and Education Quarterly, Submitted*.

Newstetter, W. C., & Hmelo, C. E. (1996). Distributing cognition or how they don't: An investigation of student collaborative learning. In D. C. Edelson & E. A. Domeshek (Eds.), *Proceedings of ICLS'96* (pp. 462-467). Evanston, IL: AACE.

Ousterhout, J. K. (1997). *Scripting: Higher level programming for the 21st Century* : Sun Microsystems Laboratories.

Papert, S. (1991). Situating constructionism. In I. Harel & S. Papert (Eds.), *Constructionism* (pp. 1-11). Norwood, NJ: Ablex Publishing Company.

Repenning, A. (1994). Programmable subsrates to create interactive learning environments. *Journal of Interactive Learning Environments, 4*, 45-74.

Roschelle, J. (1992). Learning by Collaborating: Convergent Conceptual Change. *Journal of the Learning Sciences, 2*(3), 235-276.

Scardamalia, M., & Bereiter, C. (1991). Higher levels of agency for children in knowledge building: A challenge for the design of new knowledge media. *Journal of the Learning Sciences, 1*(1), 37-68.

Soloway, E., Jackson, S. L., Klein, J., Quintana, C., Reed, J., Spitulnik, J., Stratford, S. J., Studer, S., Eng, J., & Scala, N. (1996a). Learning theory in practice: Case studies of

learner-centered design. In M. J. Trauber (Ed.), *CHI96 Conference Proceedings* (pp. 189-196). Vancouver, British Columbia, Canada.

Soloway, E., Krajcik, J. S., Blumenfeld, P., & Marx, R. (1996b). Technological support for teachers transitioning to project-based science practices. In T. KOschmann (Ed.), *CSCL: Theory and Practices of an Emerging Paradigm* (pp. 269-305). Hillsdale, NJ: Lawrence Erlbaum and Associates.

Turns, J., Guzdial, M., Mistree, F., Allen, J. K., & Rosen, D. (1995). I wish I had understood this at the beginning: Dilemmas in research, teaching, and the introduction of technology in engineering design courses, *Proceedings of the Frontiers in Education Conference* . Atlanta, GA.

Walker, R., & Guzdial, M. (Submitted). Collaborative music to motivate mathematics learning, *Proceedings of CSCL'99* . Palo Alto, CA.

Wojtowicz, J. (Ed.). (1995). *Virtual design studio*. Hong Kong: Hong Kong University Press.

Zimring, C., Khan, S., Craig, D., Haq, S.-u. -., & Guzdial, M. (1999,). *CoOL Studio: Using simple tools to expand the discursive space of the design studio.* Paper presented at the Design Thinking Research Symposium, MIT, Cambridge, MA.