

Promoting Interaction in Large Classes with a Computer-Mediated Feedback System

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ABSTRACT

Eliciting student participation in large college classes is notoriously difficult yet critical to learning. This paper describes a design experiment with a computer-mediated feedback system for promoting class interaction. We delineate specific challenges to interaction and propose design principles to address them in computer-mediated systems. A prototype realizing these principles establishes a computer-mediated channel for student-initiated feedback. Students position preset annotations (e.g., SLOW DOWN, EXPLAIN) directly on the lecture slides. The system presents an anonymized summary to the instructor in real time. An experiment in a large class validates our design and suggests new lessons for computer-mediated, student-initiated interaction.

INTRODUCTION

Students-instructor interaction is vital to student learning. However, soliciting student feedback in large lecture classes (with about 50 students or more) is challenging, and as a result, lectures tend to lack interaction [3]. Despite this problem, as educational institutions serve more students and face ever tighter resource constraints, the large lecture is likely to persist, especially at the introductory level, creating a need for innovative approaches to large class challenges.

Previous approaches to promoting interaction in large classes include new teaching methods [2, 4, 13] and computer-based systems [9, 10, 25]. (See Related Work.) We have designed a computer-mediated feedback system to promote student-initiated interaction. The system creates a parallel communication channel in the classroom, allowing students to provide feedback via networked computing devices. Students can select a region on a lecture slide and make a feedback annotation from a set of semantic categories. The instructor selects these categories which may include comments like EXPLAIN, SLOW DOWN, and QUESTION. Our work differs from existing audience-initiated feedback systems [6, 26] in

that our system provides rich context, allowing the presenter to merge context and comment to interpret the feedback. Our system is novel in empowering students to provide simple yet descriptive feedback on their own initiative.

In this paper, we present the design experiment [7] for our computer-mediated feedback system. The design experiment research process engineers a learning environment by introducing an intervention. First, the researcher studies the environment to guide design of the intervention; then, she iteratively engineers the intervention and studies its impact on the environment. In order to understand our target environment, we observed large lecture classes, collected field notes, and conducted several preliminary experiments with existing (non-computing) feedback systems [2] and with pen-and-paper versions of our system. Finally, we studied the use of a laptop-based prototype of our system in the target environment, collecting field notes, interviewing the instructor, logging system use, and surveying student participants. Our principal contributions are (1) a set of design principles based on primary challenges to interaction in large lecture courses, (2) design of a feedback system in accordance with these design principles to address the challenges, and (3) validation of the design through successful use of the system in a real, large class setting. Together, these contributions establish the value of a computer-mediated, student-initiated feedback system for large classes and sets the stage for future work exploring enhancements to the design and long-term evaluations of its use.

The paper's structure reflects the design experiment process. We begin by delineating challenges to interaction in large classes. We then show how the affordances of available technology can be synthesized in a design that directly addresses these challenges. Next, we validate our design by implementing a prototype and studying its use in and effects on a large lecture class. Our results show that students did indeed take advantage of the newly available feedback channel, and the instructor responded to the feedback, adapting presentation accordingly and creating opportunities for continued interaction. Finally, we describe future directions for this research, relate this project to prior work, and conclude.

CHALLENGES TO INTERACTION IN LARGE CLASSES

The education community has long discussed the challenges of facilitating student-instructor interaction in large classes [14, 15]. A study of 51 classes with up to fifty students (well below the enrollment of many colleges' larger classes) found that student participation drops with increasing class size [12]. In this work, we focus on the lack of student-initiated interaction in large lectures. This situation poses a serious threat to the learning environment because interaction plays an important role in student learning [21]. Based on the literature and our department's experience, we see several primary factors inhibiting student-initiated interaction in large classes:

- **Student Apprehension:** Research on communication apprehension shows that students are intimidated by the number of students in large classes [5]. Students will remain silent rather than interrupt class to ask a question they perceive as stupid or unimportant. Such feelings of apprehension are very common among college students, particularly in larger classes [5, 23].
- **Comment Verbalization:** A factor closely related to student apprehension is student ability to verbalize comments. Instructors of large classes in our department have often observed that students have trouble communicating the source of their confusion in words, a natural difficulty when working with unfamiliar material. Considering student apprehension, students who are unable to verbalize a comment are unlikely to interrupt lecture simply to announce their confusion.
- **Feedback Lag:** Timing is another critical factor affecting student participation. A fast-paced lecture can damage student participation by not leaving enough time for the student to process presented material [3], let alone interrupt with a question. Discussion with students participating in our study points to a phenomenon we call "feedback lag." Students are unsure of the value of their questions until a topic is finished. Then, when the lecture progresses to a new topic, students believe the "window of opportunity" to ask topical questions has passed and leave them unvoiced.
- **Single-speaker Paradigm:** Limited time for spoken feedback from students to the instructor is a factor intrinsic to the large lecture setting. Spoken feedback is hindered by the nature of the voice channel in the classroom [15]. When one student speaks to the instructor to ask a question or make a comment, nobody else in the class can speak, and the instructor's attention is necessarily focused on that one student. This paradigm poses no problem in a class of ten, but if each student in a class of two hundred asked even one question requiring ten seconds to articulate, over a half hour would be consumed just listening to the questions. This "single-speaker" problem clearly worsens with increasing class size.

These challenges to participation and represent the primary obstacles to interaction in the large lecture classroom. Effective approaches to addressing these problems must also consider two important design challenges. First, solutions

should require no more than marginal attention of both instructors and students, because both parties need to focus attention on the class itself. Second, given the size of the large class, solutions must plan for managing increased volumes of feedback to ensure its usefulness to the instructor.

TECHNOLOGICAL RESOURCES

The increasing presence of technology in the classroom offers new resources to meet these challenges. College campuses have begun to provide high bandwidth networking with wireless access in classrooms. Many classrooms are now equipped with data projectors and computers for instructor use in presentations. Meanwhile, an increasing number of students have portable or handheld computers of their own.

Our design for a computer-mediated feedback system exploits these resources and further assumes that the instructor uses the data projector to present shared classroom content integral to instruction. This scenario is a natural fit with slide-based presentations (e.g., using Microsoft PowerPoint), but it does not exclude the style of teaching from a blackboard. Instructors can maintain this style using, e.g., a LiveBoard [11] or a pen-based computer driving a projector. For our experiment, we established a local wireless network and provided wireless-enabled laptops to students. However, our vision is that institutions need only supply the infrastructure for our system because most students will have their own networked devices. We believe the value of the system will scale with the number of students participating, and our experiment shows that even small partial adoption has value.

DESIGN PRINCIPLES

We present a set of design principles for building computer-mediated feedback systems targeted at large classes. These principles follow directly from the challenges to interaction and design challenges discussed earlier. As empirical validation of these principles, we present results from preliminary studies and from our primary experiment (discussed later). A designed according to these principles can leverage the affordances of networked computing to address the challenges we have described and promote interaction.

Non-verbal communication

Networked computers provide an alternative to speech, sidestepping the single-speaker problem. Any number of students can provide feedback simultaneously through individual computers. If these computers share a network, a computer system can silently and unobtrusively collect the individual student feedback for the instructor. At no point in this process is exclusive control of a communication channel necessary.

Anonymity

We believe that anonymity can address the challenge of student apprehension. Indeed, across three experiments with anonymous, in-class, written student feedback (using Classroom Assessment Techniques or "CATs" [2]), we saw participation levels of over 60% out of 150 enrolled students.

Given attrition and attendance levels, the actual fraction of participating students was probably closer to 80%. In other experiments, written student feedback that was anonymous included classes of comments we had never heard spoken during our observations: one student complained of boredom and several students complimented the instructor's teaching.

Anonymizing student feedback in a computer-mediated system is simple and rapid. Digital feedback is easily separated from identifying information, and computer systems avoid pitfalls of written feedback such as recognizable handwriting.

Establishing student confidence in this anonymity may present more of a challenge. A student giving feedback on a paper form with no name attached clearly understands the protocol protecting her identity and the risks associated with that protocol. To build similar understanding of a computer-mediated system, students should be encouraged to explore the instructor interface to the feedback system.

Shared context for feedback

Students and instructors already view a shared artifact in the classrooms we are targeting, the projected display. This artifact can be used as a shared context for feedback: student's comments can be attached to text or locations from the shared view. This mechanism addresses several challenges to interaction while introducing little extra burden on students and instructors.

The presence of context scaffolds students' verbalization by giving them concrete foci for their feedback. Moreover, because the students are already attending to this context in the class, it does not burden them with new material to absorb. Indeed, many instructors in our department already provide students with pre-printed copies of the slides used in their classes.

Context also empowers students to circumvent the issue of feedback lag. As long as a student can still see the context that inspired a comment, the student can annotate that context. As long as the instructor can also still see the context, the student's comment can still spark valuable interaction. Therefore, a feedback system should keep context available long enough for students to express their comments and instructors to observe those comments.

The instructor also benefits from shared context. Like the student, the instructor is already attending to projected information. Therefore, feedback in the shared context is easy to understand. In an interview conducted after our validation experiment, the instructor was shown a student's simplified feedback icon in the context of a slide, and she was able to reconstruct the student's corresponding free-form question. On one slide, the instructor saw the icon for confusion (a circle) on the word "authorized" in the phrase "Changes can be made by 'authorized' employees." In response, she said, "I don't know if I explained authorized except that I got [the students] the idea of who should have access or has been man-

dated to have access to your information." The original student's free-form annotation was: "Who is authorized?" We expect that shared context will make understanding student feedback a simple task for instructors in many cases.¹

Rapid, automatic synthesis of feedback

To parlay student feedback into true class interaction, the instructor must be able to synthesize and respond to the feedback. Setting aside the difficulties students have in verbalizing their problems, this synthesis does not generally pose a problem for spoken feedback, as only one student speaks at a time. However, once a class uses simultaneous feedback on the scale of hundreds of students, synthesis of feedback can present a real challenge.

This challenge is not limited to computer-based feedback; any feedback system that brings together substantial, simultaneous student input faces the same difficulties. In our preliminary experiments with CATs, summarizing and understanding the 93 to 133 approximately one-paragraph student responses took between three and five person-hours. (The summarization was performed by a team of two to five readers.) Obviously, this cycle time puts CATs well outside the realm of real-time feedback tools. Other instructors have experimented with visual aggregation, e.g., by having students display cards to signal some concept or problem [3, 18]. However, these paper-based techniques threaten students' anonymity and lack the shared context described above.

Computer-based aggregation should offer real-time synthesis of feedback while protecting student anonymity and retaining shared context.

Simple interfaces

Both students and instructors are already engaged in activities that demand their attention in class. To account for the limited attention available for new tasks, both student and instructor interfaces to the system should be simple.

Value to all users

Introducing a groupware system to promote feedback spawns the new problem of securing buy-in from the instructor and students [17].² To secure buy-in from the instructor, the feedback system should support a broad set of scenarios of use, demonstrating value of the system in the immediate, short, and long term.

We believe that buy-in from the students will depend primarily on the perceived response of the instructor to feedback from the system. When asked about whether the preliminary written feedback experiments we performed influenced their instructor's teaching, most students responded that it had at least a little and a significant minority perceived a strong effect. We hoped that the computer-mediated system will have

¹Note that recovering the context of feedback anchored only by the time of its occurrence in the lecture (as in some previous work [6, 16]) might be complicated by the feedback lag effect.

²Where appropriate, teaching assistants, graders, and other staff members should also be considered.

at least as large a perceived effect, or as one student using a pen-and-paper version of the system put it, “The pen and paper method did not allow for immediate feedback, but I’m sure the electronic ones were much better.”

DESIGNED SYSTEM

We designed and implemented a prototype system based on these design principles. The system works with a slide-based teaching approach. It is composed of a student view, instructor view, and shared view. The student view allows students to annotate regions on the slide from a fixed list of possible feedback. (See Figure 1.) The instructor view is the instructor’s private interface to the system. This view is designed to be displayed on a screen visible to the instructor at the front of the classroom or on a device the instructor carries, such as a tablet PC. (See Figure 2.) The shared view is projected to the entire class and can be set to look like a “normal” slide presentation or to show some of the data presented in the instructor view.³

The student view shows the contents of the shared view with the student’s feedback superimposed. Students generate feedback from a fixed list of possible annotations which we call semantic categories. When the student right-clicks anywhere on the slide, the list of semantic categories appears. The student selects one of these by clicking. The selected annotation appears on the student’s screen at the right-clicked location and is sent to the instructor’s view. Using a small, fixed menu of categories keeps the student interface simple. Supporting annotation directly on the slide leverages shared context. In our experiment, we accounted for feedback lag by advancing the slide on the student view approximately ten seconds after the shared view, giving students a chance to decide whether to commit annotations they were considering. We arrived at this duration for lag through negotiation with the students, but we have not yet tested other possibilities. Figure 1 shows the student view with two annotations committed and a third being created.

The instructor navigates through the presentation from the instructor view. This view also shows aggregated student feedback through a combination of two mechanisms: each student’s annotation text appears where the student marked it; and multiple annotations on a single bullet (or slide region) are aggregated into a highlight on that bullet with intensity proportional to the number of annotations. To preserve anonymity, no identifying information is associated with the annotations. The highlights delineate the feedback context for the instructor. The highlights also make repeated student feedback prominent and eye-catching, alerting an instructor to vital feedback without requiring constant attention. As with the student view, the instructor view lags the shared view by a few seconds to allow the instructor to see final feedback on the old slide. Figure 2 shows the instructor view

³The shared view is currently unimplemented; for the experiment described below, we simulated the shared view and some of the timing effects described in this section by having a research team member track the projected shared view, which was driven by Microsoft PowerPoint.

with an annotated slide.

The choice of the preset semantic categories is a key parameter to the system. While we do not dictate specific categories, we do suggest four design considerations to instructors and students as they negotiate the categories to use. First, semantic categories should directly address issues of importance to the class. Second, to maintain simplicity of the interface, the number of semantic categories should be small, and their names should be short. Third, the categories should share thematic similarities to help the students and the instructor remember their meanings, reducing the attention required to use the system. In our experiments, instructors have chosen categories that represent student commentary on the slides themselves and categories that give suggestions to the instructor. Finally, the categories should include at least one option for positive feedback. We base this recommendation on our experience with a pen-and-paper version of our system where no positive category was available. In an early study, students spontaneously produced almost as many free-form, positive comments as they did in any of the three official categories.

We envision that students in a class would use the system during the course of the lecture to annotate points of confusion or interest. The instructor can monitor her view peripherally and respond immediately to feedback she considers important, either because of its nature or quantity. She can solicit feedback by asking students to spend a minute thinking about and annotating a slide. Other possible uses include incrementally improving slides from term to term based on archived student feedback, soliciting feedback on slides designed to accompany CATs, using annotations to support voting, or refining upcoming lectures based on feedback in an earlier class. These scenarios form a vital part of the system design by encouraging instructor buy-in to the system. Indeed, the instructor in our validation experiment initially perceived the system’s greatest value to be archiving feedback (to inform incremental improvements of slides for future terms).

IN-CLASS FEEDBACK EXPERIMENT

We ran an experiment with the prototype system in a large university class in order to validate our design principles and investigate what happens during actual classroom use of the system. What emerged was a strong proof-of-concept in the form of student feedback enabled by the system, instructor response to the feedback, and even secondary effects of increased conventional interaction and novel, unplanned interaction enabled by the system.

The experiment took place in a fluency in information technology class session [24]. The class was large, with approximately 120 students at the end of the term (150 at the start). Because the course has no prerequisites, the students enrolled varied widely in experience with computing and in area of study. The lecture met thrice weekly, and smaller lab sections led by teaching assistants met twice weekly. All class sessions lasted 50 minutes.

- ❖ The tracking number field is something the user cannot enter (locked field) and cannot change...
 - Place the cursor in the tracking number field
 - Unlock the field Explain
 - Assign the field a new value:


```
YYY.Text = "SCCHC" & Hex((12 * (Year(Date) - Year("02/02/02")) + Month(Date)) * 1000000 + VisitID)
```
 - Lock the field down so no changes can be made by the user
- ❖ What is the tracking number? Slow Down
 - The letters "PSHC" followed by the computer's hexadecimal encoding of the number of months since the creation of the database plus the current month number multiplied by one million, plus the VisitID
- ❖ The tracking number is reversible, but not easily associated with a person or a visit.

Slow Down
 Explain
 Question
 Cool topic!

Figure 1: A portion of the student view of the feedback system. The student has made two annotations: an EXPLAIN and a SLOW DOWN. He is in the process of making a third annotation on the word "reversible." The menu shown is the list of semantic categories — SLOW DOWN, EXPLAIN, QUESTION, and COOL TOPIC! — that appears when the student right-clicks on "reversible." Note that this student's annotations (and another student's) are aggregated on the instructor view in Figure 2.

- ❖ The tracking number field is something the user cannot enter (locked field) and cannot change...
 - Place the cursor in the tracking number field
 - Unlock the field Explain Explain
 - Assign the field a new value:


```
YYY.Text = "SCCHC" & Hex((12 * (Year(Date) - Year("02/02/02")) + Month(Date)) * 1000000 + VisitID)
```
 - Lock the field down so no changes can be made by the user
- ❖ What is the tracking number? Slow Down
 - The letters "PSHC" followed by the computer's hexadecimal encoding of the number of months since the creation of the database plus the current month number multiplied by one million, plus the VisitID
- ❖ The tracking number is reversible, but not easily associated with a person or a visit.

Figure 2: A portion of the instructor view of the feedback system. The instructor sees three student annotations: two EXPLAINS and one SLOW DOWN. The two annotated bullets on the slide are highlighted. Because the EXPLAINS coincide on one bullet, that bullet's highlighting is more prominent. Note that one EXPLAIN and the SLOW DOWN correspond to the student annotations in Figure 1.

Classroom Climate

Our class observations, instructor interviews, and surveys of the student volunteers suggest that this class suffered many of the interaction challenges discussed earlier.

The amount of student participation in the class was limited and smaller than the instructor would have liked. As the instructor said, “[The students] don’t ask questions. And so I can get through a lecture and I really am not sure how much of it they actually got.” Students, too, reported little spoken participation in class. Of 12 students who volunteered to be surveyed, 10 reported that they spoke out in class less than once a week, while two reported that they spoke about once per week. Even when asked how often they “publicly participate in any other way” — that is, excluding speaking but including, for example, hand-raising in response to a poll — only three of the 12 students reported participating more than once a week. Our class observation notes confirmed these reports. Over eight classes, we observed an average of 16 episodes of students speaking out per class. Considering the class had a regular attendance of about 100 students, these numbers corroborate the student and instructor reports of little individual student participation.

Furthermore, students reported apprehension as the dominant factor inhibiting their participation. Nine of the 12 students surveyed reported that there were times when factors kept them from participating in class. Of these nine, six cited factors that resonate with the notion of apprehension, saying for example: “Didn’t want to sound incompetent.” and “Just a little shy.”

Students also reported feedback lag as a problem. As one student put it, “the lecture was proceeding so quickly that it didn’t seem very relevant to ask a question. . . .”

Experimental Procedure

While actual classroom usage of the system occurred during one lecture, the research team held several preliminary meetings to prepare the participants. We met with the instructor three times (for a total of less than three hours) to demonstrate the system, secure her participation in the experiment, and negotiate semantic categories for the lecture. The instructor expressed doubt that she would gain much advantage from monitoring the system herself, because she tends to stand away from the computer when teaching. Therefore, she proposed that a teaching assistant (TA) monitor the instructor view and alert her to important feedback. At least one TA regularly attends class and has no specific, assigned duties during lecture. However, the instructor later asked that a member of the research team fill this mediation role, because the TA had not yet seen a demonstration of the system.

The research team also met with student volunteers for approximately thirty minutes to demonstrate the system and negotiate semantic categories. During this meeting, students were shown and encouraged to play with the instructor view as proposed in our design guidelines.

We envision that the task of negotiating semantic categories with the students would normally fall to the instructor. The time required to manage this negotiation could be amortized across many class sessions. However, the research team scaffolded category negotiation in this experiment to reduce the burden on the instructor and better understand how students and instructors viewed the categories. The final choice of categories was left to the instructor.

In this experiment, the instructor chose four semantic categories: three that suggest courses of action for the instructor and one, on advice from the research team, that expresses positive student interest. The SLOW DOWN category suggests that the instructor slow her presentation pace on a topic. The next two categories identify student confusion. Students were instructed to use EXPLAIN when confused but unsure how to guide the instructor. QUESTION was for times when the student was confused by a topic and had a specific clarifying question and suggests that the instructor stop for questions. Finally, COOL TOPIC! allows students to give positive feedback on a topic. All four semantic categories are visible as they appeared to the student in Figure 1.

For the experiment itself, 13 student volunteers were divided into two groups, seven using our feedback system and six using a pen-and-paper simulation of the system similar to what we had used in preliminary studies⁴. Unbeknownst to us until after the class, a 14th student decided to pair up with a friend on his laptop just as the class began. Each student (including the 14th) chose and recorded a code name on his or her device (whether computer or pen-and-paper). We used these code names to correlate feedback with a post-experiment survey.

One member of our research team watched the instructor view and filled the mediation role the instructor had initially envisioned for a TA. He alerted the instructor to feedback when the feedback fit two criteria: it came from the SLOW DOWN, EXPLAIN, or QUESTION categories, and the annotations appeared late enough in the instructor’s discussion of the slide to represent informed feedback. If these conditions were met, the mediator attracted the instructor’s attention when she returned to the front to advance the slides. He then pointed to one of the categories on a piece of paper to indicate the category of feedback and gestured to the instructor view screen to identify context. This research team member also maintained the delay described in our system design by waiting 10 seconds before advancing to the next slide displayed on the shared view.

Data

We collected several different types of data for this experiment. Two members of our research group had been observing this class regularly for most of the term and taking observation notes. We also took observation notes of the pre-

⁴The pen-and-paper system is a printout of the slides with a set of icons representing the semantic categories. Students use the icons *or* free-written text to make comments.

Category Type	Comp.-mediated Annotations	Paper Annotations	
		Category	Free-Form
SLOW DOWN	2	1	6
QUESTION	2	12	9
EXPLAIN	12	17	2
COOL TOPIC!	16	2	11

Table 1: The number of each type of annotation for the students using the computer-mediated feedback system and the students using the pen-and-paper system. The number of annotations for the pen-and-paper group are further divided into two categories: those annotations that were made using a semantic category and those that were initially free-form annotations (which we coded into a category).

liminary meetings leading up to the experiments. During the experiment, we had two observers in the class. We collected the artifacts generated from the six students using the pen-and-paper simulation and the system was instrumented to log the activity of the eight students using the system. After the experiment, one research team member conducted an audio-taped interview with the instructor, and all the student volunteers were asked to complete a survey online (with 12 of 14 actually completing the survey).

ANALYSIS

The design experiment provided a real-world setting to inform the design and to examine the use of the feedback system in the classroom. We were interested in observing how students provide feedback through the system and how the feedback affected the nature of interaction in the class, both conventional class interaction such as spoken questions/responses and interaction associated with feedback through the computer-mediated feedback system.

All 14 participants provided at least one annotation during the lecture. Each student using a laptop produced between one and nine annotations, while each student using the pen-and-paper version produced between seven and 15 free-form and icon annotations. Students using the paper-based system could write free-form comments on or beside the slides. We conclude that students participating in the study did indeed have feedback to provide to the instructor.

Table 1 shows the number of each type of annotation for the computer-mediated feedback system (8 participants) and for the pen-and-paper system (6 participants). Note that the students in the paper feedback group could express free-form comments, in addition to annotations in the semantic categories. We attribute the difference in the total comments of the two groups to the additional feature of free-form comments in the pen-and-paper group.

Students providing this feedback is the first step toward sustained interaction and dialogue in a class. To continue the interaction, the instructor responds to the feedback in some way. We discovered two themes in the effects of aggregated, real-time feedback on instruction and interaction. First, the

instructor responded to feedback by changing her presentation style. Second, conventional interaction remained at a level consistent with other past lectures, with additional interaction spurred by student feedback. We examine these themes in detail in the following two sections.

Instructor Response: Change in Presentation Style

The instructor changed her presentation style in response to feedback in two ways: by changing the pace of the lecture and by providing more examples and explanations when requested to do so. Evidence from class observations, student surveys, and an instructor interview support the assertion that the instructor did respond to feedback by changing her presentation style.

We witnessed a change in pace during the presentation, sparked by the feedback given by the students using the computer-mediated feedback system. The instructor asked students, “Do I need to back up or just stay here?” after receiving a SLOW DOWN message. She proceeded to explain the content on the slide once more. Also, the instructor did switch back to a previous slide twice in response to student feedback.

The instructor also responded to feedback by giving more explanations or more examples for concepts that were annotated with a QUESTION or EXPLAIN. Early during the lecture, a bullet in a slide mentioned a “tracking number.” A student annotated the tracking number with an EXPLAIN and the instructor responded, “Ah, I will come back to that question.” Upon coming to the slide with more information about the tracking number, she pointed out that she was responding to feedback and explained the tracking number in detail. During the instructor interview, she expounded on further explanations she might give on this point: “The tracking number on the code ... is something that needs to be explained a little more thoroughly... Why do packages have them? That sort of thing. You know, bring in Fed Express or something.” Another concept annotated with an EXPLAIN was the concept of batches. During the lecture, the instructor spoke about updating a student account profile and performing these updates in batches. In the interview, she later explained, “So how I dealt with it in class was to try and think of examples where that happened. They probably weren’t the best examples. So if I knew that this was a problem, I probably would change this wording [on the slide] in the future.” The instructor spoke about her reaction to another annotation, this time a QUESTION, in the interview: “I didn’t see what the question was, but we did talk about this for a while... just to say that this is the same as looking for any non-empty field.” In all of these examples, the instructor provided additional examples and explanations in response to feedback.

Overall, the instructor reacted positively to the possibilities of computer-mediated feedback, saying: “[The students] can actually say something right away, and if the teacher has the wherewithal or the time, they can actually make small im-

provements or small changes that will treat those anxieties or concerns or continue doing what they're doing that the students like."

We asked the students in the study if they perceived that the instructor responded to their feedback. Because only the feedback provided by students using the computer-mediated feedback system affected the teacher in real-time, we discuss their responses. Six of the seven students who completed the survey said the instructor did respond to their feedback. Examples of student comments:

- "Further explanations were given when asked to"
- "There was one topic in the lecture where I didn't understand something completely and I either made a remark electronically with a QUESTION or EXPLAIN and [the instructor] saw that on the laptop and she further explained the topic where it was needed."
- "I asked for an explanation on a point, and she stopped and explained it."
- "The computer guy [the mediator] told [the instructor] that there was a question and she did respond to it."

Evidence gathered from observation notes, the instructor interview, and student survey responses show that the instructor altered her presentation style in response to feedback from the computer-mediated feedback system during the class.

Conventional and Enabled Interaction

The feedback system also enabled new kinds of interaction in the classroom without any apparent negative effect on conventional interaction, i.e., spoken student participation. Table 2 summarizes levels of conventional participation and participation through the feedback system.

Conventional student participation on the day of the experiment was consistent with student participation during past lectures. There were 17 episodes of spoken participation by students on the day of the experiment, compared with an average of 12.5 per lecture for the same instructor (Instructor 2). Six of these episodes were student-initiated, compared with six episodes in general. Students participating in the study also reported how often they usually vocalize questions and comments and how many times they vocalized questions and comments during the experiment. Of the 12 respondents to the survey, 10 said they speak less than once per week normally and the other two said they speak about once per week. Two students reported speaking in class on the day of the study, one from each of the computer-mediated and the pen-and-paper groups. This level of participation is, again, consistent with the students' normal level.

The instructor characterized the level of verbal interaction as low but consistent. She compared levels of interaction during the experiment to other classes during the term: "I ended up talking more on certain slides, but still didn't get a lot of student-based, let's say, student-vocalized questions." Later, she compared spoken interaction levels in the experiment to

Category	Number for Instructor 1	Number for Instructor 2	Number for Class with FS
Total Participation	16.5	12.5	17
Student-Initiated	5.2	6	6
Comp-med Feedback	N/A	N/A	32
Paper-Based Feedback	N/A	N/A	60

Table 2: The number of times students participated on average during each lecture. The total participation is the average count per class session of student-initiated questions (excluding logistical questions such as when homework was due), student-initiated comments, and student responses. The student-initiated count is the number of student-initiated questions and comments per session. The course was taught by two instructors with Instructor 2 teaching the class session using the feedback system (FS). We observed Instructor 1 over six class meetings and Instructor 2 over two regular class meetings plus the day of the experiment.

her presentations of the same lecture during different terms: "For this particular topic, I can say that I probably had a little more student interaction than I have normally."

New interactions were also enabled through the feedback generated by students using the computer-mediated feedback system. The instructor asked for student understanding and performed student assessment during the class. For example, the instructor commented after explaining a concept during the experiment, "Hopefully that makes a little more sense, and if it doesn't, someone can chime in with another EXPLAIN." At another point, the instructor was responding to a SLOW DOWN. She asked her students, "Do I need to back up or just stay here?" After receiving no verbal feedback from the students, she went over the slide more carefully once more. The instructor also showed concern for student understanding when going over the slides during the interview. She said of the last slide presented during lecture, "So, who knows if they actually got the information they needed by the end of class. It hasn't come up across the bulletin board at all."

Overall, the feedback system encouraged the instructor to respond to students by changing her presentation style. This new communication channel in the classroom enabled students to provide feedback that they would have been unlikely to provide otherwise and spurred new interactions without any apparent damping effect on conventional interaction.

Addressing Challenges to Interaction

Our analysis shows evidence that the computer-mediated feedback system directly addressed three of the four challenges to interaction outlined at the beginning of this paper: student apprehension, feedback lag, and the single-speaker problem. On the student survey, only one student men-

tioned apprehension as a limiting factor for the day of the experiment while seven of 12 students mentioned it for past class sessions.⁵ Two out of six students in the pen-and-paper group reported suffering feedback lag on the day of the experiment, while none of the students in the computer-mediated group mentioned feedback lag. Finally, the large volume of feedback given with the system (see Table 2) suggests that the system addressed the single-speaker problem.

FUTURE WORK

This experiment suggests several refinements to the design.

One instructor concern suggests a new feature: “I felt like I responded... [but] I wasn’t sure... was it enough of a response because there wasn’t a way to tell me that ‘Ah yes, that answers the question’...” A method for students to augment or modify initial feedback may address this concern and move the system from supporting feedback alone to supporting extended, two-way interaction.

Four students’ survey responses requested the ability to give free-form comments — i.e., give feedback outside the established semantic categories. However, we are concerned that adding this feature might aggravate the problem of feedback lag. Indeed, two students in the pen-and-paper group complained of feedback lag in their survey responses. Balancing these concerns will be an important task.

In preliminary meetings with the student volunteers, several students suggested that they would feel more at ease asking questions if they knew other students in the class had questions. Allowing students to see aggregated feedback might encourage more response. On the other hand, even anonymized, exposing a student’s feedback to other students might also make that student more apprehensive.

The system currently supports instructor-initiated feedback by allowing the instructor to override the default semantic categories on any region. We would like to see how this feature works in practice. In our experiment, the instructor had a slide prepared to support a “Muddiest Point” CAT [2]: a bulleted list of topics from the lecture, each of which could be annotated with the single category MUDDIEST POINT. However, the slide was cut for lack of time.

The preliminary experiment validated the design of the computer-mediated feedback system and provided evidence for system use in the classroom. Longer term experiments, experiments with more student participants, and experiments with different technologies (e.g., handhelds with pen-based input) might expose interesting new issues. Indeed, one student reported apprehension in the survey because of the small size of the computer-mediated group: “If there were more people ... using the system, ... I would feel more anonymous and more likely to make comments.” Studying the use

⁵That one student said, “If there were more people in the room using the system, that way I would feel more anonymous and more likely to make comments.”

of the system throughout a term will provide valuable insights about the change of use over time. Along with new effects of the system on the class, larger-scale studies would also allow exploration of new uses of the system, such as archival improvement of lecture materials across terms and other scenarios described in the Designed System section.

Finally, further experiments could also focus more on the importance of specific design principles, validating them individually as factors of a successful design.

RELATED WORK

The problem of spurring classroom interaction is challenging and important, and much work has been devoted to addressing it. Overall, our system builds on previous work but stands out in accommodating student-initiated feedback within a rich, shared context and requiring little instructor effort for adoption.

Non-technological approaches to increasing interaction in large classes range from advice on establishing a conducive classroom climate to larger scale changes in teaching method and class design, e.g., active learning [4, 13] and classroom assessment techniques [2]. While valuable in their own right, success of these methods relies heavily on the instructor’s personality, talent, and time commitment, both for preparation outside class and for novel activities during class. Our system was designed to fit the popular lecture teaching style for large classes and was tested with minimal instructor and student training.

Existing technological approaches such as Classtalk [9, 10] and ImageMap [25], while promising, similarly require non-trivial changes in teaching style for effective classroom use. Most important, these approaches are designed to facilitate episodes of instructor-initiated interaction, e.g., group exercises and polling, rather than student-initiated feedback.

Brittain’s mobile phone-based feedback system [6], Flatland [27], and TELEP [20] support student- or audience-initiated feedback; ActiveClass [16] allows students to enter their questions as free-form text; and the ParcTab project [26] discussed a relevant application supporting audience feedback during presentations. Our approach improves on these systems by placing feedback in a rich shared context.

Systems such as eClass (formerly Classroom 2000) [1], NotePals [8], and “Authoring on the fly” [19] also involve enhancing classrooms with computing, but they distinctly differ from our approach in their goals of supporting notetaking and archiving of the classroom experience. Similarly, the Pebbles system [22] is focused on the problem of collaborative control of a presentation rather than on feedback.

CONCLUSIONS

We have described the design of a system for promoting interaction in large classes. Through the design and deployment of the computer-mediated feedback system, we engineered a new learning environment, providing a new medium

for student feedback and student-instructor interaction. In the process, we delineated the key challenges to promoting this interaction and grounded these challenges in literature, discussions with instructors, and observations of large classes. Our design principles, realized in an implemented system, demonstrate how the computer-mediated communication system addresses these challenges. Finally, analysis of an experiment with the prototype system showed how this design establishes a novel channel of communication in the classroom parallel to spoken feedback and effective in generating interaction.

Much work remains to be done exploring the possibilities of this design. However, the implications of the work extend already to any computer-supported system for interaction in large classes. Any such system will face these challenges and might benefit from integrating our design principles.

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