Classtalk: A Classroom Communication System for Active Learning*

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Abstract

Traditional methods for teaching science courses at the post-secondary level employ a lecture format of instruction in which the majority of students are passively listening to the instructor and jotting down notes. Current views of learning and instruction challenge the wisdom of this traditional pedagogic practice by stressing the need for the learner to play an active role in constructing knowledge. The emerging technology of classroom communication systems offers a promising tool for helping instructors create a more interactive, student-centered classroom, especially when teaching large courses. In this paper we describe our experiences teaching physics with a classroom communication system called *Classtalk*. *Classtalk* facilitated the presentation of questions for small group work, as well as the collection of student answers and the display of histograms showing how the class answered, all of which fed into a class-wide discussion of students' reasoning. We found *Classtalk* to be a useful tool not only for engaging students in active learning during the lecture hour, but also for enhancing the overall communication within the classroom. Equally important, students were very positive about *Classtalk*-facilitated instruction and believed that they learned more during class than they would have during a traditional lecture.

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An emerging technology, *classroom communication systems* (CCSs), has the potential to transform the way we teach science in large lecture settings. CCSs can serve as catalysts for creating a more interactive, student-centered classroom in the lecture hall, thereby allowing students to become more actively involved in constructing and using knowledge. CCSs not only make it easier to engage students in learning activities during lecture but also enhance the communication among students, and between the students and the instructor. This enhanced communication assists the students and the instructor in assessing understanding during class time, and affords the instructor the opportunity to devise instructional interventions that target students' needs as they arise. By facilitating a shift from a passive, teacher-centered (i.e., lecture-style) classroom, toward an interactive, student-centered classroom, a CCS helps to create a classroom environment that accommodates a wider variety of student learning styles, making the learning of science a much more positive experience for students. CCSs are unique tools that teachers can use for facilitating learning and for improving students' attitudes toward science.

This article describes our experiences over the last three years using a CCS called *Classtalk** to teach four different introductory university physics courses. In our application of *Classtalk*, students spend a significant portion of the class time working collaboratively to deepen their understanding of physics. *Classtalk* is a combination of software and hardware that permits the presentation of questions for small-group consideration, as well as the collection of answers and the class-wide display of a histogram of student answers. The display of the histogram is the springboard for a class-wide discussion of the ideas and methods used to analyze situations and solve problems. The time we devote to lecturing is decreased, while the time students devote to developing and refining their conceptual understanding is increased. The instructor's role, therefore, more closely resembles that of a coach than a dispenser of information.

We begin by summarizing the views of teaching and learning that have shaped our use of *Classtalk*. We then describe the software, hardware, and operational features of the *Classtalk* system. Next we present the instructional objectives and pedagogical strategies that undergird our use of *Classtalk*. We continue with a description of our experiences teaching with *Classtalk*, followed by a summary of students' attitudes towards the instructional approach. We close with an overview of the factors that might affect the expansion of *Classtalk* to other classes, disciplines, and institutions, and a summary of the reasons we believe that *Classtalk* can effect changes in the college lecture hall.

Current Perspectives on Learning and Instruction

The effectiveness of CCSs, as with all instructional tools, depends on the thoughtfulness of their use. Specifically, pedagogic decisions regarding the use of a CCS should be tied to educational objectives and should be congruent with one's beliefs about how people learn. In this section we provide

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* *Classtalk* is developed and marketed by Better Education, Inc., 1822 George Washington Hwy, Suite 205, Yorktown, VA 23692. *Classtalk* has been used to teach psychology and physics at Carnegie–Mellon University, and physics at Christopher Newport University, Harvard University, The Ohio State University, and the University of Cincinnati.

an overview of current perspectives on learning and instruction that have informed the choices we have made in our use of *Classtalk*. We start by describing constructivism, a fundamental viewpoint about the nature of knowledge acquisition. Although constructivism explains our view of our students as learners, it is not so useful in making day to day decisions about instruction. For such guidance, we draw from three distinct areas of educational research, also described herein.

Constructivism

Constructivism is a set of beliefs about knowing and learning that emphasizes the active role of learners in constructing their own knowledge (Anderson, 1987; Jonassen, 1995; Resnick 1983, 1987; Schauble, 1990; von Glasersfeld, 1989, 1992). The construction of knowledge is viewed to be the result of a learner's attempts to use his/her existing knowledge to make sense of new experiences. This entails both the modification of concepts and the reorganization of knowledge structures. Although the construction of knowledge can be facilitated by instruction, it is not the direct consequence of instruction. Since knowledge construction depends on the extant knowledge of the learner, different individuals will come away from an instructional experience with their own unique understanding, no matter how well the instruction is designed, and no matter how much effort the individuals devote to making sense of what they have seen and heard. Constructivism stands in stark contrast to the view of learning in which individuals passively receive well organized knowledge.

Although learners must construct their own knowledge, a significant portion of an individual's knowledge is constructed in response to interactions with other human beings. From a social constructivist perspective, most learning is socially mediated (Brown, Collins & Duguid, 1989; Cole, 1985; Hewson, Kerby & Cook, 1995; Lave, 1988; Vygotsky, 1978). Certainly the influence of human interactions on knowledge construction is so pervasive that a proper understanding of learning cannot be achieved without taking into account its social dimension. Since much learning is done within a social context, it becomes important to understand how dialogue between a teacher and students, and among students, can be used to enhance student learning.

Relevant Research in the Learning of Science

Issues raised in the following three areas of science education research have implications for the construction of knowledge and are particularly relevant to our use of *Classtalk*. They are a) research on misconceptions, b) research on the knowledge structures of experts and novices, and c) research on the effects of motivation and classroom contextual factors on learning.

Misconceptions. Ideas that are in direct conflict with scientific concepts are known as misconceptions or alternative conceptions and have been identified across many scientific domains and across all age groups. For example, misconceptions have been documented in physics (Hestenes, Wells & Swackhamer, 1992; McDermott, 1984; Mestre & Touger, 1989), astronomy (Lightman, Miller & Leadbeater, 1987), biology (Wandersee, 1983), earth science (Pyramid Film and Video; Sadler, 1987), and mathematics (Clement, 1982a). Misconceptions can develop from a learner's attempts to understand both in-school and out-of-school experiences. In many instances misconceptions are deeply seated and difficult to dislodge. Despite indications of some initial understanding of scientific concepts immediately following traditional instruction, many misconceptions resurface weeks later (Clement, 1982b; Halloun & Hestenes, 1985). Evidence suggests that some misconceptions can interfere with subsequent learning and that considerable effort is required on the part of the learner to effect conceptual change (Hestenes & Wells, 1992).

Knowledge Structures. Studies of experts and novices in a variety of domains suggest that the skillful use of domain knowledge to reason and to solve problems requires more than the construction of individual concepts. Knowledge needs to be interrelated and organized within mental structures that permit its efficient recall and effective use (Glaser, 1992, 1994). In a domain such as physics, for example, experts tend to organize their knowledge around a relatively few major concepts and principles that can be used to solve a wide range of problems. Such concepts and principles serve as categories for binding together knowledge about related ancillary concepts, problem situations, and mathematical procedures (Chi, Feltovich & Glaser, 1981). The pieces of knowledge related to a particular major concept or principle are strongly linked and are accessed together (Larkin, 1980, 1981, 1983). The expert has knowledge structures that have evolved over a considerable period of time to serve higher level cognitive functions within the domain, such as explaining, reasoning, problem solving, and teaching. Not unexpectedly, compared to that of experts, the knowledge store of novices contains many fewer knowledge elements, is inter-linked by many fewer relationships among elements, and is not organized around major concepts and principles to the same degree as experts (Chi et al., 1981; Dufresne, Gerace, Hardiman & Mestre, 1992). Instead, many novices rely on more superficial categories (e.g., objects in problems and physics terminology) for organizing knowledge, categories that cannot be easily related to the approaches that can be used to solve problems.

Motivational Beliefs and Classroom Contextual Factors. The construction of knowledge is not a dispassionate process. The level of engagement and persistence on a task is related to the learner's motivational beliefs (Pintrich & De Groot, 1990; Pintrich & Schrauben, 1992). Students who are more motivated are more likely to persevere in the difficult cognitive processes necessary for creating and organizing knowledge. Motivation has been described as having two components, one related to the value of a task and one related to the learner's beliefs about his or her capabilities or likelihood of success (Pintrich, Marx & Boyle, 1993). Tasks that are more likely to result in learning are those that are perceived as interesting, important, doable, and profitable (Pintrich et al., 1993; Strike & Posner, 1992).

The process of knowledge acquisition is also influenced by classroom contextual factors (Garner, 1990). For example, interactions with teachers and peers can help create an atmosphere of commitment to understanding. An optimal learning environment, then, should incorporate engagement with teachers and other interested learners.

Teaching Science from a Constructivist Perspective

Although constructivism does not prescribe how one should teach, it does carry implications for curriculum and instruction. It suggests that students would benefit from learning opportunities that not only expose them to new information or experiences, but also enable them: a) to examine their own ideas, b) to determine the extent to which the new experiences make sense in light of these ideas, c) to consider a number of possible alternative explanations for what they have experienced, and d) to evaluate the usefulness of a number of different perspectives. In addition, we believe that if instruction is to help students organize the knowledge they construct, some learning activities should challenge them to select, identify, and defend their choices of concepts and principles for use in a given context. Other tasks should ask students to describe the relationships between concepts. All of the above processes are more likely to take place if students are actively involved in *doing* something other than listening (Anzai & Simon, 1979). A constructivist perspective points to the need for instructional formats that allow for active learning, where students are engaged in writing, talking, describing, explaining, and reflecting — processes that do not normally take place in a traditional lecture hall.

Examples of some active learning formats that work well in a large lecture hall are cooperative group work (Johnson, Johnson & Smith, 1991), class-wide discussions (Gullette, 1992), and interactive lectures (Mazur, 1993; Sokoloff, 1994; Van Heuvelen, 1991). In cooperative groups, students work together to answer questions and solve problems. In class-wide discussions, they present and defend their own views, and critique the views of other students. In interactive lectures, the instructor not only presents material, but also elicits questions and comments from students, stopping periodically to pose questions for students' consideration. These instructional formats allow teachers to probe for students' conceptual understanding and allows students to work on tasks that require them to explore their reasoning, not just to give their answers. For these instructional formats to be effective, students and teachers must have the opportunity to formulate their thoughts, questions, and answers in order to ensure a greater depth of discourse. Although cooperative group work gives both students and teachers time to process their thoughts, during class-wide discussions and interactive lectures instructors should take special care to allow ample time for students to process and reflect on questions and comments (Tobin, 1986).

Potential of a CCS for Impact on Present Practice

There is evidence that, for many students, traditional lectures are not effective for constructing conceptual understanding (Bonwell & Eison, 1991). The trouble with lectures is <u>not</u> that they prevent the construction of meaningful knowledge, but rather that they accommodate only those students who make sense of ideas while listening and taking notes. Other students need the opportunity to reflect on the material by discussing it, writing about it, and using it to solve problems (Claxton & Murrell, 1987). One way to increase student engagement in their own learning during the lecture hour is to relegate the coverage of facts to the students' independent work time and devote the lecture time to helping students hone and integrate concepts. This can be accomplished by integrating cooperative group work, class-wide discussions, and interactive lecturing into the class session. An instructional format with these components allows students to reflect on their own thinking, to detail their own understanding, to listen to each others' ideas, and to ask questions for clarification. Despite some successful attempts to make physics lectures more interactive (Mazur, 1993; Van Heuvelen, 1991; Wilson, 1994) the impact on college-level science instruction has not been large. Of course there are strong influences contributing to the inertia of current teaching practices in higher education: a) the tendency to teach the way we were taught; b) pressure on faculty to focus on matters other than instruction, namely research; c) the lack of professional development geared towards teaching (either prior to or after appointment to a teaching position); d) the push to cover an enormous amount of content matter; e) fear of losing control over the content that is covered; f) concern about management of students in a large lecture hall while teaching in an alternative format; and g) memories of past failures in implementing teaching innovations without adequate support. Any format that is to replace the traditional lecture must address these legitimate concerns of instructors.

A CCS-supported interactive lecture offers the opportunity to create a truly active learning environment in a large group format and addresses some of the concerns listed above. In terms of faculty resources, there is an initial time commitment necessary to become comfortable with the system and to design appropriate questions for student consideration. After this point, it is as economical of faculty time as traditional lectures. Teaching in a style that promotes students' active engagement with the material does not require either compromise in the amount of content covered during the semester or loss of control over content.

In a CCS-facilitated lecture, there is still a place for presentation of material or demonstrations to ensure that students are exposed to specific ideas. For example, a short presentation can be used to set the stage for having students answer a particular set of questions or to clarify issues raised by students following the class-wide discussion of a question. Or instead of simply showing a demonstration and explaining what it means, an instructor can use a CCS to ask students to predict the outcome and explain their reasoning before they see it. Another way to ensure that students are exposed to specific ideas is to make the ideas the focus of questions that students can work on in small groups. Further, the instructor can hold students responsible for reading factual material before coming to class — a task students might be more willing to do if it is clearly relevant to their in-class work.

Beyond these concerns over faculty time and coverage of course content, the use of a CCS can help with the management of alternative instructional strategies in the lecture hall. For example, the CCS aids in the formation of cooperative learning groups, as students are tied to one another in purpose (they work on a question together), have limited resources (all share one input device), and are held individually accountable for the information (students can be required to input individual responses that the instructor can see). The CCS also helps the instructor re-focus students on whole-group instruction by allowing for the display of histograms of class responses to a question at the end of the group work time.

Before detailing our experiences using a CCS in our physics lecture halls, we will elaborate on the characteristics of the particular CCS we use (*Classtalk*) and our rationale for using it the way we do.[1]

The Classroom Communication System Classtalk

The classroom communication system *Classtalk* is the product of Better Education, Incorporated. In brief, the system consists of a number of student input devices networked to a central computer under the instructor's control as represented in Figure 1. From the central computer the instructor can present questions or tasks to the audience by displaying them on a monitor or projecting them onto a screen. The network is used to download tasks to the student input devices, return student responses to the instructor's computer, and if desired, provide response-specific feedback to the student. Programming contained in the central unit permits the instructor to examine the collected responses, display the results to the audience, and store them for future analysis.

All components of the *Classtalk* system are undergoing continuing development. Many modifications have been made and new features have been added since we began this study. It is not our intention here to provide an exhaustive exposition of the system's capabilities, but rather only to present a succinct description of the features we have used.

System Hardware

The *Classtalk* system has three major components: student input devices, a central computer, and a smart network connecting them. Each student input device consists of a Hewlett-Packard 95LX palm-top computer, which has a full QWERTY keyboard and a 40 × 16 character LCD screen. Programming loaded into the 95LX enables up to four students to sign-on to a single input device. The network consists of a master network server and a number of network adapter boxes, each of which can serve up to four palm-top computers. It is the job of coding stored in the adapter boxes to establish a communication protocol with each of the palm-tops. (Subsequent modifications to the system permit the use of a Texas Instruments TI85 graphing calculator as the input device in conjunction with an elaborated network design.)

[1] Although there are other examples of CCSs with various operational characteristics (see, for example, Stetten & Guthrie, 1995), from this point forward we will discuss only the *Classtalk* system.

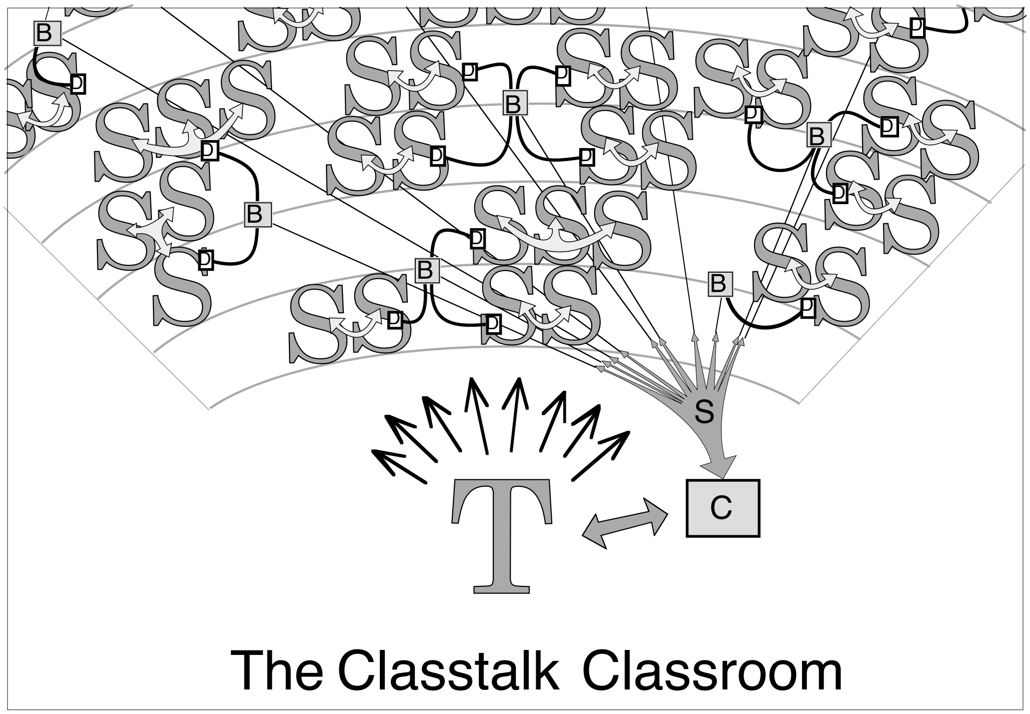

Figure 1: Representation of *Classtalk* classroom. Students work in groups of up to four, with each group sharing an input device (D) networked to a central computer (C) under teacher control. The network consists of a master network server (S) linked to network adapter boxes (B), each of which can serve up to four input devices.

The current *Classtalk* configuration requires, as the instructor's computer, an Apple Macintosh (SI or better) with 8M RAM and an additional video card. The video card is used to drive the display monitor and/or projector. The primary monitor is used as a teacher's console and displays all of the control options together with a screen region that may or may not show the same image presented to the audience.

System Software

From the instructor's point of view, it is the control environment provided by the software resident on the central computer that constitutes the heart of the *Classtalk* system. Within this environment the instructor can create tasks or questions in a variety of styles, present them to the audience by projection or by downloading questions and/or text to the palm-top computers, permit response for a selected interval of time, govern the type of responses allowed, analyze responses in assorted fashions, and project the results of the analysis to the audience. All of these functions can, in principle, be performed during class time. Question generation, however, usually requires sufficient reflective thought that we have found it is better to have tasks prepared prior to class time. (We do, however, occasionally create or edit questions during lecture in response to students' comments.)

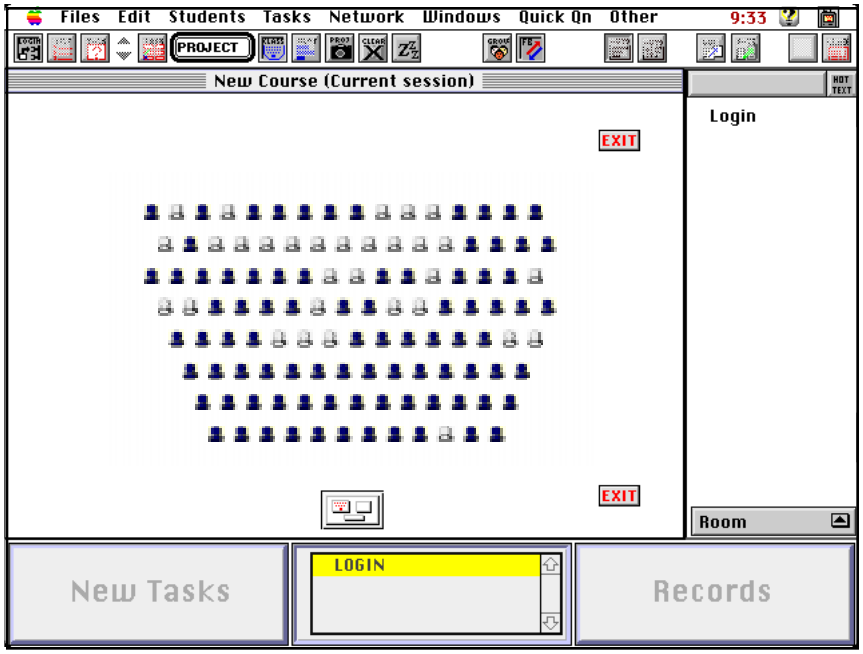

Figure 2: Screen face of the central computer in the Active Tasks mode. Screen displays the seating positions of students signed on to the *Classtalk* system. The seating arrangement depicted is input at start-up and corresponds to the actual lecture hall being used. The name of a student at a particular seat location (and other relevant information) can be obtained by clicking on the seat icon. After a question is sent, as each student inputs a response, his/her seat icon changes to a color corresponding to his/her answer.

The *Classtalk* environment is subdivided into three modes: Active Tasks, New Tasks, and Records. Each mode has an associated virtual monitor that, upon request, may display a list of tasks, a specific task, an iconic image of the classroom showing occupied seats color-coded by student response, a list of responses, a histogram of responses, other analysis data, or a summary of student performance on all tasks given during that class. Which of the three virtual monitors is displayed on the instructor's screen or, independently, on the audience screen is at the discretion of the instructor.

Active Task Mode. The Active Tasks mode is the central or focal mode of any currently active class session. Here, the instructor can allow students to sign onto the system and can view an image of the classroom that maps the seating positions of students (Figure 2). The instructor can also display either an active task (Figure 3), a histogram of class responses (Figure 4), or other analysis data. Student seat icons change color as students enter their responses, indicating the answer each student gave to the current question. As student responses come in, the system compiles them in a histogram, binning them either according to a predetermined set of criteria included with the task or according to clusters of responses determined by the program at execution time and ordered by frequency of occurrence. Responses to active tasks can be viewed and analyzed in this mode, but tasks are initiated from the New Tasks mode and finished tasks are stored in the Records mode.

New Task Mode. This mode provides all the necessary functions required for the generation, management, and storage of tasks. Usually they are created prior to class and are stored in a *taskfile* that is loaded at start-up time. Tasks can be generated within the environment (using a limited text editor and some basic graphics tools) or they can be imported from some external editor or graphics program (e.g., *Canvas*™). Each task is an individual question or an associated set of questions treated as a single entity. In addition, existing questions can be assembled into sets or extracted from sets, ordered, listed, and/or printed. There is additional information stored with each question, such as any text for downloading to student-held devices, possible student responses, and any feedback to be associated with each response. Responses to questions may be a single character, a number, or a text string.

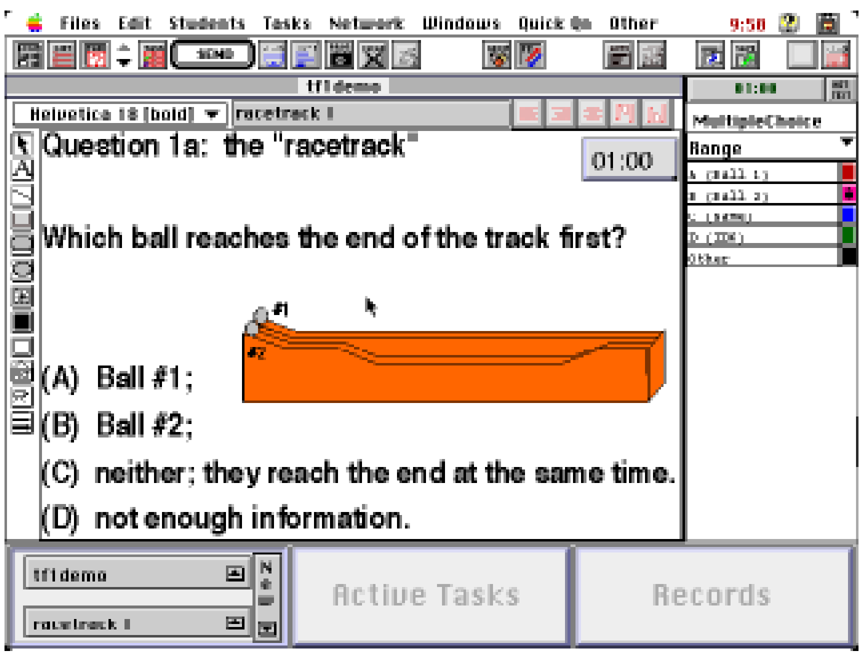

Figure 3: Screen face of the central computer in the New Tasks mode. Screen displays a task that was used in the math/science majors' course. Upon sending a question a dialog box appears allowing the instructor to set various options such as feedback, student response (i.e., *individual*, *group*, or *group with dissent*), and timer.

Records Mode. Finished tasks are relegated to the Records mode. All of the data associated with the class, the task itself, and student responses to the task are stored in raw form. All tasks previously used during the current class session are available for re-examination in Records mode.

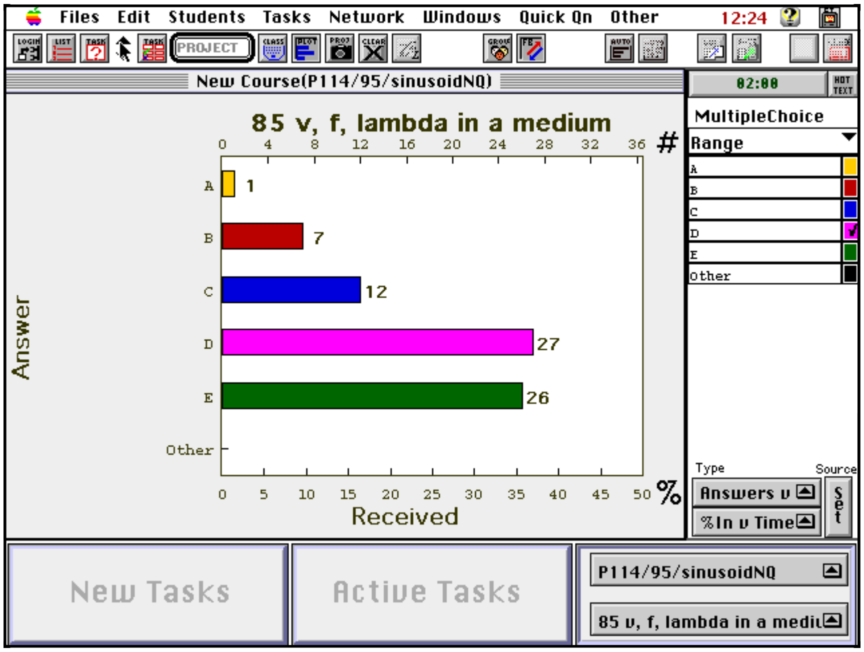

Figure 4: Screen face of the central computer in the Records mode. Screen displays a histogram of class responses from a question used in the non-science majors' course that was retrieved from a *sessionfile*. The histogram can be obtained by pre-selecting bins or by having the program automatically bin in order of frequency of response. Histograms can also be obtained in the Active Tasks mode for the currently active task.

Classroom Operation

At the beginning of each class session, students are allowed to sign on to the system. The sign-on feature is launched as a background activity, freeing the environment for other uses. The ability to sign-on automatically terminates after a pre-set (but adjustable) time interval.

Once the instructor has selected a task with the environment in the New Tasks mode, it can be "sent" to the students. Sending a task causes the simultaneous performance of several actions. If the task is a single question these operations are: display of the question on the audience monitor and/or projector, download of associated text to the student devices, the bumping of any previous task still resident in the Active Tasks mode to the Records mode, and finally the appearance of a dialog box that enables the instructor to set the time interval during which responses will be accepted. The only changes that occur if the question is a question *set* is that the entire set of questions is downloaded to the student input devices, and students must read and respond to the questions appearing on the screen of the palm-top computer, though they can work back and forth between the questions at their own pace. Once a task has been started, students must respond to the question or the entire set of questions in the allotted time.

In addition to limiting the time for responses to be entered by the class, when activating a task the instructor can specify one of three response options: *individual*, *group*, and *group with dissent*. As the name implies, if a task is sent indicating that an *individual* response is required, each student must separately input his/her answer to the question. When a task is sent with a *group* stipulation, then the system will accept only a single answer per input device and that answer is attributed to every student signed on to that device. With the *group with dissent* option, members of the group who disagree with the majority are allowed to enter an independent response.

From within the Active Tasks mode, the instructor can view the accumulation of responses in real-time. Once the allotted time has expired, *Classtalk* software analyzes the responses in the form of a histogram showing frequencies of responses, which the instructor can display to the audience. After a task has served its purpose, it can be relegated to the Records mode or left in the Active Tasks mode to be displaced to the Records mode by sending another task. Upon completion of the class session the program creates a *sessionfile* containing all of the student data, tasks, and responses. *Sessionfiles* can be reloaded at a subsequent time for examination, and response data can be written to an external file for further analysis.

Our Use of Classtalk

This section describes our educational goals and objectives, our choices in how to use the *Classtalk* system, and our experiences in the classroom. Our instructional goals and objectives drive our pedagogical decisions. We continue to reflect upon our experiences and to experiment with what works best for us. We will point out our concerns as well as our successes as we proceed through the description of our experiences.

Educational Goals and Objectives

We have four broad educational objectives: 1) Students should know and understand definitions, terminology, facts, concepts, principles, operations, and procedures; 2) Students should be able to communicate what they know to others; 3) Students should know how to apply what they have learned to analyze situations and solve problems, extending this ability to increasingly complex situations; and 4) Students should develop the ability to evaluate critically the usefulness of various problem-solving approaches. Our goals are to advance our educational objectives for our students and to structure our classes in such a way that maximizes the likelihood that all students achieve these objectives. We strive to create an environment in the lecture hall that is conducive to student participation in the processes of articulating, reflecting on, and evaluating their ideas. We do not take for granted that students will acquire or enhance these habits of mind working independently outside of class.

The Structure of Instruction with Classtalk

We structure a class period around the cooperative group solution and class-wide discussion of questions. The closure of one question often leads to the presentation of a second so that instruction has a cyclical quality, as depicted in Figure 5. For ease of presentation, we break down this *question cycle* into 7 stages: 1) question generation and selection, 2) sending the question, 3) cooperative group work, 4) collection of answers, 5) histogram display, 6) class-wide discussion, and 7) closure. These stages constitute flexible guidelines for the flow of instruction rather than an instructional recipe that is rigidly followed. Dashed lines on the figure show some possible variations in the way one can proceed. For example, students can be given time to work and respond individually before they do so in groups. Results of the class-wide discussion may lead to the generation or selection of a completely different question than the instructor anticipated before class. Within this instructional format, the amount of time the instructor spends presenting information is cut to approximately one-third of the class period. The other two-thirds of the class is spent by students in small group discussion or in discussion as a whole class with the instructor serving as facilitator.

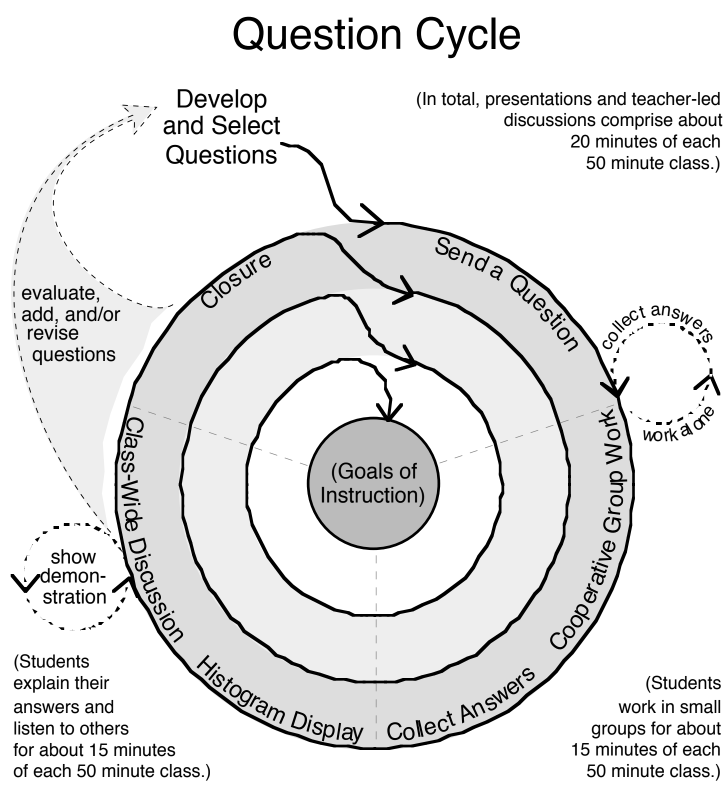

Figure 5: The structure of *Classtalk* instruction. Most class sessions can be broken down into cycles containing seven stages, beginning with Question Selection and Generation and ending with Closure. This *question cycle* was not a rigid format followed every class. Dashed lines represent examples of possible variations in the cycle.

Summary of Experiences Teaching with Classtalk

The description of our experiences is based on the following data sources:

- In-depth, end-of-semester interviews with 18 of the 74 (female) students enrolled in the spring 1995 section of a service course for non-science majors entitled, *The Physics of Sound with Applications for Speech and Hearing*.

- In-depth, end-of-semester interviews with 7 of the 33 students enrolled in a first-semester mechanics course for math and science majors offered in the fall of 1994.
- A group interview with 9 math and science majors who had used *Classtalk* for 3 consecutive semesters.
- Field notes from all sessions of the non-science majors' course and periodic sessions of the math/science majors' courses.
- In-depth interviews with the two instructors (who are two of the co-authors of this article) of the four *Classtalk*-taught courses (three for math/science majors, one for non-science majors).
- End-of-semester questionnaires in all four courses.

In the remainder of this section we recount the experiences of the instructors and the students for each stage in the question cycle.

Question Development and Selection. Most of our questions are designed either to make students aware of their own perspectives and the perspectives of others, to reveal points of confusion and misunderstanding, to make distinctions between ideas, or to elaborate on their understanding of a concept. Such questions generated more lively debate among students, raising more issues of conceptual understanding, than did computational questions. A student in the non-science majors' class described the questions in this way:

> "... sometimes you don't get it if you just do the specific [computational] questions. But when you do conceptual questions, you see how everything fits in. And it helps you relate that to other things."

We organize our questions so that they build on each other and on previously learned material. For example, questions may be designed and ordered so that students must apply a concept or principle in contexts that are increasingly different from those in which the concept or principle was initially learned. The purpose of extending the context is to help students explore the limits of their current understanding of a concept or principle, and move toward an understanding that is less context dependent. Organizing groups of questions in this way provides students with several opportunities to consider and use the targeted concepts. We have found that as we proceed through a group of questions students demonstrate increasing ability to use the targeted concepts in their explanations and to distinguish conditions under which the concepts could be applied, even when they are often less able to answer the later questions correctly due to the unfamiliarity of the contexts. We found that crafting a coherent group of questions took us more time than did preparing a traditional lecture on comparable material.

Sending the Question. Although sending the question with the *Classtalk* system is a simple procedure, there is instructional planning that occurs at this step. The decisions that a teacher makes with regard to ordering instruction and selecting the option for student responses have implications for the depth, the quality, and the dynamics of the group work that follow.

When questions were sent after the presentation of material or demonstration, students tended to refer back primarily to what they had just seen and heard. Their responses provided us (as instructors) with feedback about the clarity of the presentation. Although we sometimes used questions in this way to check for understanding, we preferred to use an instructional sequence that required students to engage in more reflective thought. That is, we tended to send questions before a presentation, so that students had to pull ideas from various prior experiences (e.g., readings, lectures, other courses, previous class-wide discussions, or personal observations). In this case, students' responses gave us (and them) information about their preconceptions of the ideas involved. We found this latter sequence more useful for shaping instruction.

When a question is sent, the instructor also selects the option for how the group must answer. We typically used either the *individual* or the *group with dissent* option. Although we did not see any differences in the depth of discussion of the physics concepts between these two options, we did see differences in the degree to which students made a commitment to their own ideas. As one physics/astronomy major said:

> "With individual response, you have to be more certain of your answer. When it's group with dissent it's a little easier to just go along with the group."

There is no clear evidence, however, that this commitment to a particular response has significance for learning. Early in the semester we used *individual* response more often, but as the semester progressed and students became practiced at working with their group members, we shifted toward using the *group with dissent* option.

Cooperative Group Work. Although we describe the cooperative group work and the ensuing class-wide discussion separately, they function together to clarify and improve students' conceptual understanding by allowing them: a) to articulate their current thinking, b) to reflect on their own ideas and the ideas of others, c) to elaborate on their thoughts, and d) to evaluate the usefulness of a number of different perspectives. The cooperative group work is distinct from the class-wide discussion, however, in that it affords all students the opportunity to discuss their own ideas or questions, regardless of whether or not they are comfortable presenting their ideas to the entire class. Here we describe the nature of this group work.

After a question was sent, students worked together to answer it in groups numbering two to four (although there were occasions when a student in the math/science majors' course worked alone). They consulted one another and, if necessary, their notes or textbooks. Rarely was it the case that group work consisted solely of "stronger" students tutoring other members of their groups. All students in a given group participated in a variety of ways — sometimes asking questions, at other times explaining, describing, or adding information. They discussed their reasoning and the multiple ways to proceed in answering a question. Although students are focused on answering a specific question, in our approach we place the greater emphasis on expressing the logic behind their answers. This process helps students to become aware of their own ways of thinking and of alternative ways of thinking as articulated by others.

Depending on the difficulty of the question, students worked together from 2 to 10 minutes with an average of about 5 minutes per question. Since they were typically given 2 to 3 questions each class period, they were engaged in this cooperative group work for up to 1/3 of the class time. We used the group time to monitor students' engagement both in order to determine when to stop and collect their answers, and to organize our thoughts for the class-wide discussion. For both student and teacher this represents quite a departure from their actions in a traditional lecture.

There is a great deal of variation in reasoning from group to group and from question to question. Questions designed to challenge prior assumptions led students to state their intuitions about the problem situation. The math/science majors (and later on in the semester, non-science majors) tended to back up their intuitions with physics concepts that supported their ideas. Early on in the non-science majors' course, students were not so likely (or so able) to select and apply physics concepts and principles in this way. Some cited facts from prior lectures or readings, others spent time looking through the course notes expecting to find answers. In all cases, both math/science and non-science majors were attempting to apply what they had learned, heard, or read to the new question or problem.

As the semester progressed, we saw students use more physics reasoning in their groups. Students also perceived this change. One student reflected on her reasoning in the following way:

> "Well, I think that at the beginning of the semester I just relied a lot more on...my intuition. ...sometimes I can figure out [the most likely answers] without working them out when he gives the choices. But I think now... I write it all down and try to figure it out... Sometimes I do it more than one way... just to see what I come out with. I can play devil's advocate for myself."

In most groups we observed, students typically articulated possible approaches for answering a question, after which, at least one person in each group would propose an argument that would bring all members to agreement (though not always on the correct answer). Whether students were right or wrong, when they subsequently worked on a related question, they demonstrated a better ability to use appropriate terminology or procedures.

In their groups, students were expected: a) to consider questions that went beyond the usual request for facts or formulaic solutions, b) to take greater responsibility for knowing factual information from their reading, and c) to negotiate working relationships with group members. We spent time explaining our objectives and expectations, modeling problem-solving skills, and discussing things that might help their groups work better. For the most part, students met these challenges well.

Some students, however, ran into difficulties. For example, a student in the math/science majors' course was frustrated by the *Classtalk* questions. She felt they were meant to be tricky and would have preferred questions that gave her procedural practice. She said:

> "At first I liked *Classtalk*, but as time went on, I got more and more frustrated with the questions. They're somewhat ambiguous. I keep doubting my ability to reason them out... I understand that in the long run, questions that get at misconceptions are probably more helpful, but I'm not there yet. I'd rather have a mix of questions, with more straightforward questions [than we have been given]."

One student in the non-science majors' course seemed to prefer having the group work focus on questions that came directly from the lecture without having to draw on material she was responsible for learning on her own:

> "I like when he talks about the material and then he'll give us a question and then maybe go on to, like, a different part of what we're learning and then a question."

Another student in the same course was able to meet the expectations of independent work, but reasoned more slowly than the other two group members. She did not have the time to examine her own thinking during the group work. As she put it:

> "...they'll get the answer and they'll start talking about it and I'm still trying to figure it out. ...sometimes I tell them, 'Can you wait, like, a few more minutes before you start discussing it and then I can get the answer as well?'... For the most part, though, they've helped me... I feel like it takes me a little bit longer."

She and her group members never worked out this problem of shared air time.

Overall, students were engaged in their groups in the kinds of activities that we believe to be important for their learning. We did not expect that all students would come to clear, scientifically valid answers during this collaborative work. Rather, we hoped that through their group work, students would at least be able to identify the questions that needed to be addressed. For the most part, everyone had reached a point where they could engage in a meaningful discussion of the original question.

Collection of Answers. On the surface, the collection of answers merely marks the end of the cooperative work time. But there are other things that occur during, or as a result of, this minute or two when students are entering their responses. Most students interviewed indicated that the need to enter their answer pressured them to commit to an answer. Observing the students' answers as they came in helped us determine the level of student understanding and gave us time to consider how to initiate the ensuing class discussion.

Histogram Display. Displaying the histogram of class responses has the effect of re-focusing student attention to the front of the room. Typically, both students and instructor spent about 10 seconds processing the information contained in the histogram. Projecting the results not only served to make an orderly shift back to whole-class instruction, but also provided an agenda for the class-wide discussion. In most instances, all represented responses were discussed either by having a student present his/her reason for the answer or, in those cases where no proponent would volunteer, by having a student explain why he/she thought that a particular response was incorrect.

Knowing the distribution of class responses was important to the great majority of students. In interviews, students commented that it helped them to see how they were doing in relation to the class and how the class fared as a whole. They reported that such information made them feel better about their capabilities. Some students remarked that being in the majority gave them the confidence needed to speak out in class. In fact, in the non-science majors' course, the first person to speak up in the class-wide discussion represented the majority position in approximately 75% of the questions. A few students said that, even when wrong and in the minority, they derived solace from the fact that others had made the same selection. Only a few of the students interviewed said that they did not feel affected by the histogram. We believe that students' stated interest in how the entire class performed is a reflection of their perception of the class as a community of learners. Seeing the histogram of class responses, then, helps to develop an atmosphere where learning is taken seriously.

Class-Wide Discussion. The class-wide discussion shares many of the goals of the cooperative group work, and both give students the opportunity for active participation. Even though not everyone actually speaks out during a class-wide discussion, we observed that students remained engaged in this stage of the question cycle. If students are to volunteer in this discussion, they must feel comfortable presenting, defending, and critiquing positions in the presence of the whole class. Here we look at some factors that affect whether or not students speak up, indicate what we did to encourage students to contribute, describe the nature of the class-wide discussion, and recount some typical student reactions to it.

Over the course of the semester, 65% of students in the non-science majors' course and 80% to 95% of the students in the math/science majors' courses spoke out during discussion. Although most students contributed to the class-wide discussion, others did not. There were three different reasons that students gave for not speaking up in class: 1) they were shy and never spoke up in a large group; 2) they found the lecture hall to be intimidating; and 3) they lacked confidence in their answers or in their reasoning.

Other students were not shy about speaking up or found that something helped to build their confidence. For example, students cited their selection of the majority response, their work with their group members, and the reassuring nature of their professor as factors that helped them feel comfortable contributing to the larger discussion. One student who often spoke up in class had this to say about an instance when the cooperative group work had been omitted from the question cycle:

> "... and it was one of those individual ones — you know, that you couldn't discuss it. And I was like 'I'm gonna answer,' and I didn't. I was really intimidated."

In order to encourage students to contribute in the class-wide discussion we did the following: a) We explained our objectives and expectations for the class-wide discussion, b) we tried to create a personal atmosphere (e.g., by using students' names, which can be found on the *Classtalk* seating display), and c) we communicated to students that they would not be judged by the scientific value of their answers or by the insightfulness of their questions (e.g., by attending to all answers in a respectful, straightforward manner).

In general, the time spent on class-wide discussion ranged from two to fifteen minutes per question, with an average time of about five minutes. During the discussion as few as one student responded if there had been general agreement as to the correct answer and reasoning. When there was less agreement, there were as many as ten students contributing to the discussion of a single question. For most questions, there were students who would speak out a number of times in a dialogue with the professor.

When the original question was to predict the outcome of a demonstration, the class-wide discussion was broken up by showing the demonstration itself. (See Figure 5.) Before showing it, students discuss the reasons for their predictions. Afterwards, they become more focused on trying to reconcile what they saw with what they had expected to see. These discussions were often much longer than typical ones.

Most often we initiated discussions by simply asking for a volunteer to state the reasoning underlying his/her selection or by asking for a volunteer to speak to a particular selection. Although we continually attempted to widen the number of students who volunteered to speak out in any given class, we did not put any students on the spot by calling on them when they did not volunteer to speak. Instead, we asked for a "fresh voice" or invited someone to speak in support of, or in opposition to, a particular response. We did not end the discussion just because a sound line of reasoning had been presented. Rather, when it seemed that all views had been articulated, we checked with students to see if there were further comments to be made. Sometimes the discussion ended after a student presented an argument with which most other students agreed. Other times it ended after all selected answers had been examined and the students remained divided about the correct answer; in these cases the closure stage was used to sort out the conflicting views.

It is important that the instructor manage the discussion to keep it progressing smoothly, while avoiding making the discussion teacher-centered — a huge temptation for most teachers. For example, the instructor needs to promote discussion when students are reluctant to present their views. We found it helpful to wait patiently, allowing periods of silence of ten seconds or more (occasionally reaching over twenty seconds) for students to volunteer to speak. The instructor must help students clarify their reasoning when they find it difficult to express themselves. One way we did this was by paraphrasing the student's comments and then checking with the student to see if we had stated their ideas accurately. Sometimes we found it valuable to write out a summary of what the student had said (either on a transparency or on the board). Doing so seemed to help clarify lengthy or complex explanations. It also provided a permanent record to which students could compare other arguments, and it helped us to model how one might organize the answer to a particular question.

During the class-wide discussion the types of arguments presented by students varied in style, depth, and validity. For the most part, the type of reasoning exhibited by students was similar to that described in a previous section on collaborative group work, albeit the reasoning was more focused and better organized during the class-wide discussion. We found that students were able to present and defend opposing points of view. They showed the capacity to find specific flaws in the arguments of other students. They were also capable of supporting positions taken by other students, sometimes using a completely different line of reasoning to arrive at the same answer. Finally, when students changed their minds about their answer to a question they were able to articulate the reasons for the shift in their thinking.

Students not contributing to the class-wide discussion appeared to remain focused, as evidenced by their taking notes or commenting to group members. We have never seen a student doze off during *Classtalk*-facilitated instruction. Students' descriptions of their own experiences during class-wide discussion support our assessment that they were following the discussion. A student in the non-science majors' course said:

> "...let's say someone says a part of the answer that I thought was right, but I don't agree with the other part. And then somebody else says something and I agree with part of that. I can put the two ... together and be like, 'Yeah, that's what I meant. They said it right.' So, that definitely helps."

In their interviews, students generally expressed positive opinions of the class-wide discussion. The majority of students indicated that they were comfortable speaking out in class. Students usually expressed that they were interested in listening to and evaluating arguments presented by other students, and most thought that doing this was valuable for learning and helped build confidence in their own understanding. As one student in the non-science majors' course put it:

> "...[the instructor] could get up there and explain [the reasoning]..., but when someone — even if they have it wrong — when they're working through it, you're like, 'Oh, that's what I did.' And then when he says 'Well, think of it this way' and it turns around, you can turn around your thinking too. It's not just always getting the correct explanation up there, but that's helpful too. But, I think when you see someone work through it on their own it's helpful."

Despite general agreement about the value of the class-wide discussion, there were situations about which students voiced concern. For example, they became frustrated if discussions went on too long without bringing new ideas to light, or if a student, who was apparently unprepared for class, kept prolonging a discussion. These situations clearly point to the need for the instructor to manage the class-wide discussion and bring it to closure when it seems that all views have been presented and further discussion is not fruitful.

Closure. The closure stage is carried out by the instructor and entails summarizing, clarifying, and emphasizing the main points behind the question or problem (e.g., the underlying concepts and principles, procedures, terminology, etc.), as well as embedding this understanding into the wider context of the course. If consensus was reached on a valid and appropriate line of reasoning, the instructor simply reiterated the major themes. When the class-wide discussion ended in unresolved differences of opinion, the instructor took one of a number of approaches. One strategy was to present a simpler, but related question (usually without *Classtalk*) that students were able to solve correctly, and then to draw comparisons between the two questions. Another strategy was to discuss the strengths and weaknesses of the competing arguments. In some cases, when the instructor presented or revisited a demonstration it seemed to help solidify the new understandings. In others, the instructor backtracked to clarify previously covered material that was related to the current confusion. Although implementation of some of these strategies required teacher-led presentations, they were almost always interactive.

Sometimes we used the closure period to extend the breadth of students' understanding by asking "what if" questions about the original situation (e.g., how would the answer have changed if certain parameters increased? decreased? etc.). In this way, closure of one question cycle was often used to set the stage for the next question. On rare occasions the original question was re-sent to determine the effect of the class-wide discussion and closure.

Student Perceptions of and Attitudes about Classtalk-facilitatedInstruction

The vast majority of students expressed a high degree of satisfaction with our use of questions, cooperative group work, class-wide discussions, and interactive lectures. They found that in using the *Classtalk* system, the lecture hour was more enjoyable and that the class did not "drag." The histograms in Figure 6 show combined responses to several end-of-course evaluation questions taken over two years from both the non-science majors' class and the math and science majors' year-long physics course.

Students perceived differences in what and how much they learned between traditional lectures and our *Classtalk*-facilitated classes, as the following two quotes from students in the non-science majors' course illustrate:

> "...in most courses, I'm almost always just writing notes down — too fast to even think about it. And so that... sometimes the notes don't even make sense, because I left out words... And even if they do make sense, I have to totally relearn them. Nothing sinks in during class. So I really like physics because I kind of absorb it as I go along. So that when I leave class I have a clear understanding of what we did in class... [With] the *Classtalk* questions... you have time to think about it and to talk about it... Without *Classtalk*, I think if he just lectured, I think I'd still be confused at the end of a class..."

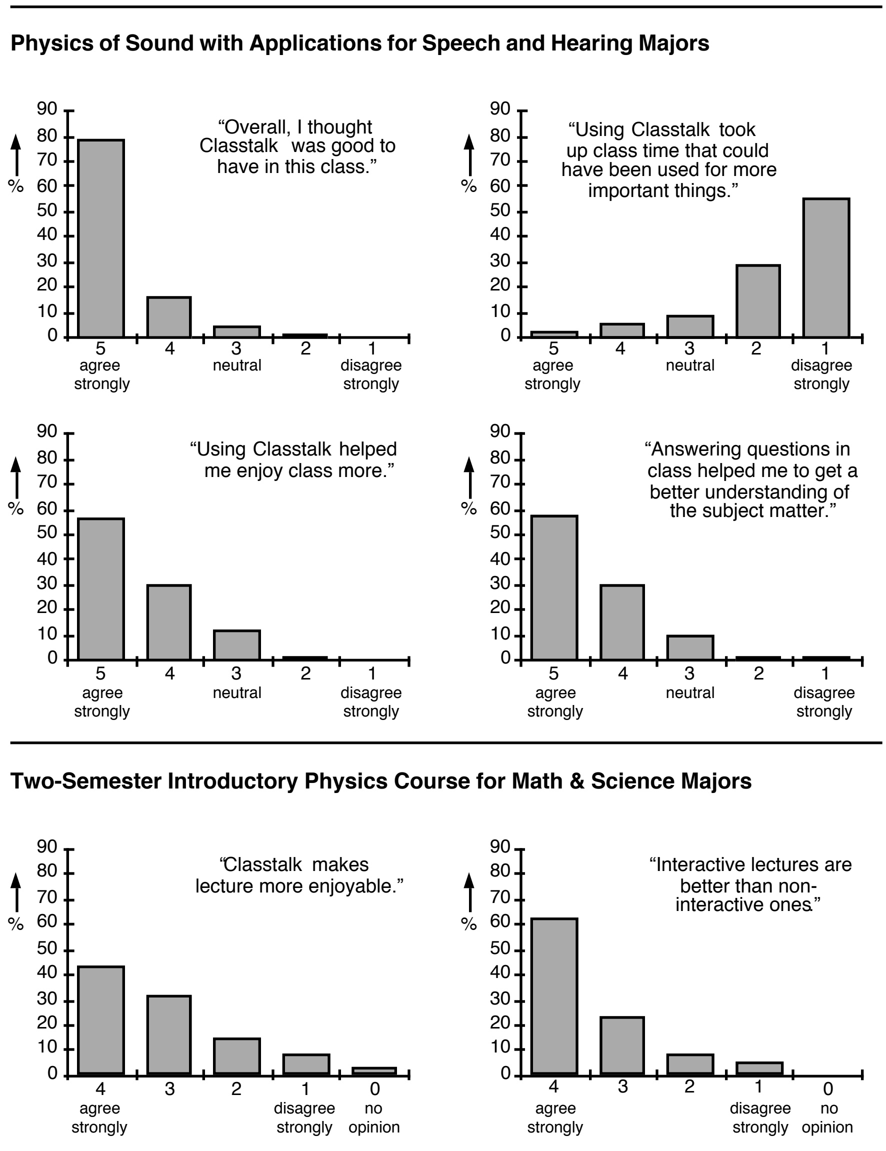

Figure 6: Histograms of student attitudes concerning *Classtalk*-facilitated instruction. Results are based on questionnaires administered at the end of the courses listed above.

> "...if I took the notes in class and I went home, two days later when I went to do the homework, [the material] wouldn't really be fresh in my mind. ... I wouldn't have had that kind of interaction with it right away."

Students thought that the types of questions we used were helpful. A student in the non-science majors' course said that she understood the concepts well from the assigned reading but admitted that:

> "I wouldn't know how to apply [the concepts]... The *Classtalk* questions in lecture show me ways that they'reapplied."

Students' satisfaction with the *Classtalk*-facilitated courses was not attributed solely to our use of the technology:

> "...a lot of it's [the instructor's] style. He said in the beginning he wasn't going to just lecture to us. We have more give and take. We're able to give him a lot of feedback. I feel very comfortable asking him questions... He really seems like he cares..."

> "I still hold the same interest when we don't have [*Classtalk*], because he still puts the questions up there, and we still have to answer them... The only difference is you're just putting in an answer. When I'm confused I like to find out what other people have put... I like it. I think that when it is there it's a plus, but when it's not there, class is still interesting."

For some students, however, they perceived that the technology was crucial to the success of their group work:

> "...when the computer's not there, we're not all involved... Someone who understands it just does it and then explains it, and... people just agree... When *Classtalk*'s there, people are, at least in my group, they're much more concerned about if they have the right answer."

Regardless of the reasons, students were very satisfied with the *Classtalk*-facilitated courses. From our perspective, the *Classtalk* system aids in the delivery of instruction aimed at promoting active learning.

Expanded Use of Classtalk

The use of *Classtalk* here at the University of Massachusetts is being expanded in three different directions — to even larger lecture courses that we will teach, to courses taught by other physics faculty, and to courses within other disciplines. Each type of expansion has its own set of challenges and pedagogic constraints. As instructors new to *Classtalk*-facilitated instruction reflect on the educational needs of their students and on their own educational goals and objectives for the course, they must select instructional formats to meet these demands. Each individual instructor will make different choices about how to use the system, but *Classtalk* is flexible enough to accommodate many different teaching styles, instructional formats, student needs, and educational goals.

There are a number of factors that might inhibit new instructors, departments, and institutions from making the transition from lecture-style classes to *Classtalk*-facilitated ones. In the remainder of this section, we present some of the psychological and economic factors that are relevant to this transition.

Psychological factors

Many faculty visitors to our lecture halls have expressed an interest in our use of the *Classtalk* technology. Individuals who are interested in using *Classtalk* as we have described it would do well to reflect on their willingness to make the shift to a more student-centered and interactive style of teaching. The effectiveness of *Classtalk*-facilitated instruction depends on more than good technical application.

In our use of *Classtalk* there is a high degree of unpredictability and a different pace to the class, as students express their points of view and struggle with the material. During a typical lecture, there are few classroom-management issues; with *Classtalk* there can be many. Not everyone will find it easy to make the transition from pure lecturing to using *Classtalk*-facilitated, interactive instruction.

Students must also struggle to make the transition to a *Classtalk* classroom. Some students, especially many of the stronger math and science majors, have done well under traditional instruction and might not appreciate the value of a more interactive format. What students must do during class is very different. They can no longer sit passively, drifting in and out of focused attention, listening to the lecturer and jotting down notes. They are pushed to articulate their thoughts and to make a commitment to a particular line of reasoning. Our approach also demands many changes in how students work and study. For example, they no longer have copious lecture notes they can pore over on their own; they must rely much more on the textbook as a reference. They must learn how to work and communicate in cooperative groups. They must learn how to process explanations and distinguish between them. Students need encouragement and support in order to complete this transition.

We are planning to use *Classtalk* in class sessions having two to three hundred students. Although we have not found students to be resistant to the shift to *Classtalk*, the largest class that we have taught had only 80 students. We anticipate that when *Classtalk* is used in larger classes, the range of student reactions will widen, and classroom-management issues will become increasingly important. An even smaller fraction of students will be able to share their reasoning during the class-wide discussion. These are just some of the factors that might hinder a smooth transition to the use of *Classtalk* in a larger lecture hall.

Economic factors

Institutions interested in using *Classtalk* (or any CCS) must make a financial investment, not only in equipment, but possibly also in additional technical and instructional support staff. For example, technical support is needed to maintain the equipment. Instructional support may be needed to help teachers make changes in the way they teach. Without adequate support, the economic investment in technology is difficult to justify.

Adequate space and equipment can be a limiting factor as well. In our case, the network has been installed in only one lecture hall, which limits the number of classes that can be taught using *Classtalk*. Depending on demand and location, each lecture hall in which *Classtalk* is installed might need a separate central computer. If different departments wish to use the system, they must decide whether it is better to install systems in lecture halls that are local to each department or to share resources.

Students may also share part of the economic burden. As mentioned briefly, in the latest version of *Classtalk* students are required to provide their own TI85 calculators as input devices. This may be an unwarranted expense, unless the TI85 is also used in related courses, which happens to be the case here at the University of Massachusetts.

ConcludingRemarks

Despite these factors which might discourage someone from using *Classtalk*, we remain optimistic about its potential to help transform the college lecture hall. Using active learning opportunities that are geared toward understanding and applying concepts appears to make science courses more interesting for students. Although it is possible to incorporate active learning into the classroom without using a CCS, we believe that our use of *Classtalk* helped us in two important ways: 1) it was useful as a classroom-management tool, and 2) it provided a mechanism for enhanced communication. In this section, we elaborate on these uses of *Classtalk*, as well as on how these affect students' motivation and attitudes toward science.

Classtalk is an effective classroom-management tool, allowing us to create a lively and rich learning environment without losing control of the class. Cooperative learning, class-wide discussions, and interactive lecturing are formats that are usually time-consuming and can lead easily to reduced coverage of material. But with our use of the *Classtalk* system, students' attention can be quickly, but gently, diverted from one task to the next without any significant loss of instructional time.

Using *Classtalk* greatly enhances communication among students and between students and the teacher, increasing active engagement during class and affecting both learning and instruction. As a result of improved student–teacher interactions, teachers can tailor instruction to meet a wider range of student needs. Instead of polling just a fraction of the class to assess the current state of knowledge and understanding, a teacher using *Classtalk* gets immediate feedback about everyone in the class. In the *Classtalk* classroom, student–student interactions occur when they work in small groups, when they see the histogram of class responses, and when they listen to one another during the class-wide discussion. Everyone in the class is involved, not just the outspoken few. Everyone is trying to "make sense" of the subject; everyone is practicing how to reason about, analyze, and evaluate physical situations. As shown by interviews, students realize the effect this has on their understanding, and they perceive that their problem-solving skills are improving.

Using *Classtalk* also improves students' attitudes and motivation toward science. Their satisfaction with our courses is in contrast to recent research on undergraduate students' attitudes toward large introductory science courses. Many undergraduates leave the sciences, not because of lack of ability or personal motivation, but rather, because they see other disciplines as more interesting, because they are dissatisfied with the quality and impersonal nature of the instruction that they receive, or because of the time required to keep up with large amounts of fact-based information (Seymour, 1995; Tobias, 1990). Further, many who left the sciences indicated that conceptual difficulties in their science courses often became debilitating because they were not addressed in a timely fashion (Seymour, 1995).

With *Classtalk* we can address these attitudinal issues. Students are working on questions that probe their conceptual understanding and their ability to connect ideas, rather than on questions that ask them to memorize lots of seemingly unrelated facts and equations. Points of misunderstanding and confusion are revealed and addressed immediately and in a non-evaluative way. Students are not in competition with each other to get the “right” answer; they are helping each other learn. Many students reported that they made new friends in class and studied with them outside of class. *Classtalk* helps us to create a friendlier environment — a place more conducive to learning and more enjoyable for both students and teachers.

The last three years teaching with *Classtalk* have been challenging and exciting. The most important result of our work in developing our use of *Classtalk* is that students are engaged in the kinds of activities and are exhibiting the kinds of behaviors that we value for learning. We hope that, as a result, they develop skills that will be useful throughout their lives and are encouraged by the progress that they show in understanding their own thought processes, in learning how to work cooperatively with each other, and in making sense of the physical world.

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