USING TECHNOLOGY TO IMPLEMENT ACTIVE LEARNING IN LARGE CLASSES*

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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 seven years using a CCS called *Classtalk*[1] to teach eight different introductory-level physics courses at the University of Massachusetts in Amherst. This system has also been used in introductory courses in biology, economics, and sociology.

[1] *Classtalk* is developed and marketed by Better Education, Inc., 1822 George Washington Hwy, Suite 205, Yorktown, VA 23692 USA.

1. 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 an overview of a perspective on learning and instruction that has informed the choices we have made in our use of *Classtalk*. We start by providing a brief description of the elements of constructivism that are basic to our approach. Although constructivism provides a fundamental description of the nature of knowledge acquisition, it must be augmented before it is useful for making day-to-day decisions about instruction. For such guidance, we draw from three distinct areas of educational research, also described in this section.

1.1 Constructivism

Constructivism is a set of beliefs about knowing and learning that emphasizes the central role of learners in constructing their own knowledge (And87, Jon95, Res83, Res87, Sch90, vGl89, vGl92). 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 involves both the modification of concepts (i.e., knowledge elements) and the reorganization of knowledge elements and structures. Although the construction of knowledge can be facilitated by instruction, it is not the direct consequence of instruction. Because knowledge construction depends on the extant knowledge of the learner, each individual will come away from an instructional experience with different knowledge and a different 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 and well presented 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 (Bro89, Col85, Hew95, Lav88, Vyg78). 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. Because so much learning is done within a social context, it becomes important to understand how communication between a teacher and students, and among students, can be used to enhance student learning.

1.2 Relevant Research in the Learning of Science

Issues raised in the following three areas of science education research have implications for the process of constructing 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 (Hal85b, Hes92b, McD84), astronomy (Lig87), biology (Wan83), earth science (Pyr, Sad87), and mathematics (Cle82a). 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 (Cle82b, Hal85a). Evidence also suggests that some misconceptions can interfere with subsequent learning and that considerable effort is required on the part of the learner to produce conceptual change (Hes92a).

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 (Gla92, Gla94). In a domain such as physics, for example, experts tend to organize their knowledge around 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 (Chi81). The pieces of knowledge related to a particular major concept or principle are strongly linked and are accessed together (Lar80, Lar81, Lar83). 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 (Eyl84). 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 (Chi81, Duf92, Har89). Instead, many novices rely on superficial categories (e.g., objects in problems and terminology) for organizing their knowledge. These categories cannot be easily related to the methods used to solve problems, and consequently lead to inefficient and unproductive problem-solving approaches among novices.

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 (Pin90, Pin92). 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 (Pin93). Tasks that are more likely to result in learning are those that are perceived as interesting, important, doable, and profitable (Pin93, Str92). The process of knowledge acquisition is also influenced by classroom contextual factors (Gar90). 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.

1.3 Teaching Science from a Constructivist Perspective

Constructivism and cognitive research findings cannot be used to prescribe how one should teach science. Nonetheless, they do carry implications for curriculum and instruction. Together, they suggest that students would benefit from opportunities to process knowledge: examine their own ideas, check whether new experiences make sense, consider possible alternative explanations for what they have experienced, and evaluate the usefulness of different perspectives. If instruction is to help students organize their knowledge, it must challenge them to select, identify, and defend their choices of concepts and principles for use in a given context, as well as 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 (Anz79, Gam87).

A constructivist perspective points to the need for instructional formats that encourage greater participation by students in writing, talking, describing, explaining, and reflecting — activities that do not normally take place in a traditional lecture hall. A major obstacle to creating an active-learning environment in traditional lecture halls is that these activities can be difficult to manage in moderate to large enrollment classes. Our experience with CCSs has convinced us that it can be an effective tool for implementing active learning, even in classrooms with as many as 300 students. As elaborated below CCSs have a number of features that can help the teacher manage in-class activities and promote increased student participation.

2. 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. From the central computer the instructor can present questions or tasks to the audience by displaying them on a monitor or by 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. We will not attempt 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. The reader who is uninterested in the hardware and software descriptions can skip to section 3 without significant loss of continuity.

2.1 System Hardware

The *Classtalk* system has three major components: student input devices, a central computer, and a smart network connecting them. In the original version the student input devices consisted of a Hewlett-Packard 95LX palm-top computer, which has a full QWERTY keyboard and a 40 × 16 character LCD screen. Subsequent modifications to the system permit the use of a Texas Instruments graphing calculator (models TI-82, -85, -86, and -92) as the input device. Up to four students can sign-on to a single input device. The network consists of a master network server and a number of network adapter boxes. Coding stored in the adapter boxes serves to establish a communication protocol with each of the 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 might or might not show the same image presented to the audience.

2.2 System Software

From the instructor's point of view, it is the control environment provided by the software run from the central computer that constitutes the heart of the *Classtalk* system. Within this environment the instructor can (a) create tasks or questions in a variety of styles, (b) present tasks to the audience by projection or by downloading questions and/or text to the input devices, (c) permit response for a selected interval of time, (d) govern the types of responses allowed, (e) analyze responses in assorted ways, and (f) 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 that it is better to have tasks prepared prior to class time.

The *Classtalk* environment is subdivided into three modes: Active Tasks, New Tasks, and Records. Each mode has an associated virtual monitor that, upon request, is able to 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 represents the seating positions of students. The instructor can also display either an active task, a histogram of class responses, or other analysis data. As students input their responses, their seat icons change color, indicating the answer each student gave to the current question. As student responses are received, the system compiles them into a histogram, placing them in bins either according to a predetermined set of criteria included with the task or according to clusters of responses determined by the software at execution time and ordered by frequency of occurrence. Responses to active tasks are 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 of the functions needed 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 or imported. Each task is an individual question or an associated set of questions treated as a single entity. 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 might be a single character, a number, or a text string.

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.

2.3 Classroom Operation

At the beginning of each class session, students are required to sign on to the system. The sign-on feature is launched as a background activity and 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. 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. Once a task has been started, students must respond to the question 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.

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.

3. Overview of CCS Use

Seven years ago the University of Massachusetts Physics Education Research Group (UMPERG) began a joint venture with Better Education, Inc. to explore the pedagogical potential of this new technology. The resulting synergy has allowed UMPERG to explore the effective implementation of the technology by applying findings from cognitive science research to instruction. Thus far, the collaboration has resulted in several articles (Duf96, Leo96, Mes97, Wen97), and the reader is referred to these for greater detail than can be provided here.

Presently there are two *Classtalk* installations at UMass, one in a lecture hall with a capacity of 120, and the other with a capacity of 300. Eight different physics instructors have used one or both of the systems. Of the eight introductory physics courses using *Classtalk*, UMPERG members introduced *Classtalk* into six of them, and then later handed five of these courses over to another instructor. Naturally, instructors are somewhat idiosyncratic in their use of the system. The instructional approach described below is the one fostered and encouraged by UMPERG. Although developed for physics instruction, we believe the approach is appropriate for all disciplines.

Typically, all of our courses are run more like an interactive workshop than a traditional lecture course. Students are expected to read portions of the textbook before each class period, and class time is devoted to developing and refining conceptual understanding. Approximately one-third of the class time is spent with instructor-initiated presentations (e.g., demonstrations and mini-lectures), one-third with students working collaboratively in groups, and one-third with class-wide discussions. Our instructional goals and objectives drive our pedagogical decisions.

3.1 Educational 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. 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.

3.2 The Structure of Instruction with *Classtalk*

The class period is structured around the cooperative group solution to 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 1. For ease of presentation, we break down this *question cycle* into 7 stages: (1) question generation and selection, (2) presenting the question, (3) collaborative 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 might 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.

4. Classroom Implementation: The Question Cycle

In this section we elaborate the seven steps in the question cycle just outlined. Our presentation is based on experience in the six courses UMPERG has taught using active-learning strategies. Although the student profiles in the courses have differed in terms of interest, motivation, and receptivity, we focus here on our general observations and experiences. For a specific example of classroom implementation, see Leo96.

- Question Generation. A pivotal aspect of our instructional strategy hinges on generating questions that enhance our instructional objectives. Questions are usually generated prior to class, although one can generate and present "spontaneous" questions during class. We have found that some types of questions advance our objectives better than others. Although we use them occasionally, we find that computational questions are not optimal for generating lively discussions, or for enhancing our instructional objectives, because students often prefer to work alone with their calculators to generate an answer. On the other hand, we have found conceptual questions to be more effective. It should be noted that "conceptual" does not imply "abstract." The more concrete the conceptual question, the easier it is for students to make progress discussing them, especially for non-science and engineering majors. For example, questions that probe for misconceptions generate very productive group and whole-class discussions. Sets of related questions that probe for student understanding of a principle/concept in increasingly complex situations are also very effective for helping students discern the contexts and conditions under which the principle can be applied. Question difficulty also plays an important role—if questions are too easy, they bore students, while if they are too difficult, they frustrate students. Questions of medium-level difficulty appear to work best, because they generate enough variation in student responses to spark interest in finding out the reasoning leading to the correct answer.

- Presenting a Question. Presenting a question consists of selecting and projecting a question for students to work on. Because students are expected to read the textbook prior to class, questions are most often presented with minimum preliminary introductions to the relevant topics. Students are expected to draw on the readings, prior knowledge, other courses, previous class-wide discussions, or personal experiences and observations in formulating a response to the questions.

- Collaborative Group Work. Both collaborative group work and the class-wide discussion (described below) work in tandem to help achieve our objectives of having students verbalize their own reasoning and having students evaluate each others' reasoning. Unlike the class-wide discussion where only a few students present their reasoning, group work allows all students to articulate their reasoning and to receive feedback from group members. By consulting their textbooks, their notes, and each other, group work results either in arguments leading to the answer or in the identification of issues and/or confusion that could be addressed in the whole-class discussion. Group work also gives students an opportunity to practice their explanations in preparation for the whole-class discussion.

- Collection of Answers. The collection of answers signals the end of group work. The instructor sets a time limit (typically 1½ minutes) for students to enter their answers, and selects the mode in which the answer should be entered (i.e., individual responses, or group answer with or without dissent). As the answers are received by the central computer, the students' seat icons indicate the answers they chose via a color scheme matched to the possible selections; this allows the instructor to gauge the level of student understanding and to begin to formulate ways of conducting the ensuing class-wide discussion.

- Histogram Display. Displaying the histogram of student answers helps bring students' attention to the front of the class and helps complete the transition to whole-class discussion. In interviews we have conducted with students, the vast majority state their keen interest in knowing the distribution of class responses — they wish to know not only how they answered relative to the whole class, but also how the whole class answered. The histogram also serves to give some students enough confidence to speak out in class. Most often, the first student to volunteer an explanation comes from the majority bin in the histogram. Some students stated during interviews that, even when wrong and in the minority, they derive solace from knowing that others made the same selection and likely used the same erroneous reasoning.

- Class-Wide Discussion. The class-wide discussion is initiated either by asking for a volunteer to state the reasoning underlying their answer or by asking someone to address a particular answer on the histogram. The discussion continues until consensus is reached or until the instructor judges that little progress is being made; in the latter case, the closure portion is used to resolve major confusion. The instructor moderates the discussion, not giving away when arguments are correct or erroneous. Generally students are able to present and defend their reasoning, as well as find flaws in the arguments of others. Students are also capable of supporting the arguments presented by other students, sometimes using an entirely different line of reasoning. When students change their minds after hearing an argument or explanation, they are generally able to articulate what compelled them to do so. During interviews following the completion of the courses, the situations about which students voiced the most concern are discussions that go on too long without bringing any new ideas to light and discussions prolonged by a student who is obviously unprepared.

- Closure. The closure stage is used to recap the class-wide discussion. When consensus is reached, closure might entail a summary of the arguments raised, pointing out the strengths and weaknesses of the arguments, or embedding the question answered and arguments made in the wider context of the course. When no consensus is reached, the instructor can try one of several strategies, such as asking a simpler question and drawing comparisons between two questions, or presenting a demonstration, or giving a mini-lecture on the topic causing the confusion. Often during closure the instructor asks “what if” questions about the original problem (e.g., how would the answer change if a certain parameter is increased?). The closure stage is also used to prepare for the next question and the next cycle.

5. General Discussion

We have described one approach for incorporating active learning in lecture courses. Although our approach makes use of a new technology (CCSs), we view the technology as facilitating instruction rather than being essential to it. Others have shown different ways of incorporating active-learning strategies (Hel92a, Hel92b, Law91, Maz97, Mel96, Sok94, Sok97, Ste95, Van91, Wil94), both with and without technology.

Perhaps the most important feature that would be missing from our approach if we were to abandon the use of *Classtalk* is the ability to display histograms of student responses. The histogram supports active learning in a number of ways. (1) Without the histogram, going from group work to a discussion would be extremely difficult, particularly in large classes. It provides a mechanism for teachers to manage the transition from group work, which is uncontrolled and clamorous, to a class-wide discussion, which requires order and a degree of quiet. Therefore, the histogram makes it practical to have students do group work in a large-lecture setting. (2) The histogram informs teachers about student responses so that they can take the responses into account as they direct the follow-up discussion. Therefore, the histogram can make the discussion more efficient and effective. (3) The histogram is of great interest to students and can serve as a significant motivating factor in focusing the attention of students on the subject matter being explored. Therefore, students continue to be engaged, even after the group work has finished. (4) When students see that other students have answered a question the same way that they did, they are often more willing to volunteer their reasoning during the class-wide discussions. Therefore, the histogram promotes participation. (5) Together with group work and class-wide discussion, the histogram promotes self-awareness in students and permits teachers and students to gain a greater appreciation of the range of explanations used by students. Therefore, the histogram is at the heart of students becoming aware of their world views and modifying them.

It might seem that all instructors should be using a classroom communication system in their courses, but learning how to use a CCS is not easy. First, instructors must learn how to operate the system. This involves not only creating questions and feedback prior to class, but also running the system during class. Second, they must develop the management skills needed to keep the class interesting, orderly, and efficient. During a traditional (teacher-centered) lecture, there are only a few classroom-management issues; with *Classtalk* there can be many. There is a high degree of unpredictability and a different pace to the class, as students work in groups, express their points of view, and struggle with the material. Third, instructors must learn how to create good questions — questions that will not only stimulate interest, interaction, debate, reflection, and learning, but also that can be dealt with in a reasonable amount of time.

Students must also struggle to make the transition to a *Classtalk* classroom. Some students, especially those with strong math and science backgrounds, have done well under traditional (lecture-based) 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 resource. They must learn how to work and communicate in cooperative groups. They must learn how to interpret explanations and distinguish between them. Students need encouragement and support in order to complete this transition.

Most students and instructors need to give themselves sufficient time to grow into their new roles, and for some, it might take a course or two before they are accustomed to the new approach. The more experienced *Classtalk* instructors admit, however, that they cannot return to a lecture format, because they have become so used to getting feedback from their students in such a timely manner. Students also recognize that their learning has improved as a result of the interactive classroom, and many try to bring interactivity into their other courses. For us, the unpredictability of an interactive class has rekindled our interest both in teaching and in learning about students' thought processes.

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 might be needed to help instructors make changes in the way they teach. Without adequate support, the economic investment in technology is difficult to justify. Adequate space and equipment might be a limiting factor as well. In our case, the network is installed in only two lecture halls, which limits the number of courses that can be taught using *Classtalk*. Depending on demand and location, each lecture hall where *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 close to each department or to share resources.

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

6. Concluding Remarks

Despite the factors that 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 both students and teachers. Although it is possible to incorporate active learning into the classroom without using a CCS, we believe that our use of *Classtalk* helps us in two important ways: (1) it is useful as a classroom-management tool, and (2) it provides a mechanism for enhanced communication. In this conclusion, 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 <u>everyone</u> 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 a lack of ability or personal motivation, but for other reasons: (a) they see other disciplines as more interesting, (b) they are dissatisfied with the poor quality and impersonal nature of the instruction that they receive, or (c) they do not want to spend the time required to keep up with large amounts of fact-based information (Sey95, Tob90). Further, many who leave the sciences indicate that conceptual difficulties in their science courses often became debilitating because they were not addressed in a timely manner (Sey95).

With *Classtalk* we can address these attitudinal issues, and create a classroom environment that is based on constructivist epistemology and cognitive research results. 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 to learn. Many students report that they have made new friends in class and study 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 several 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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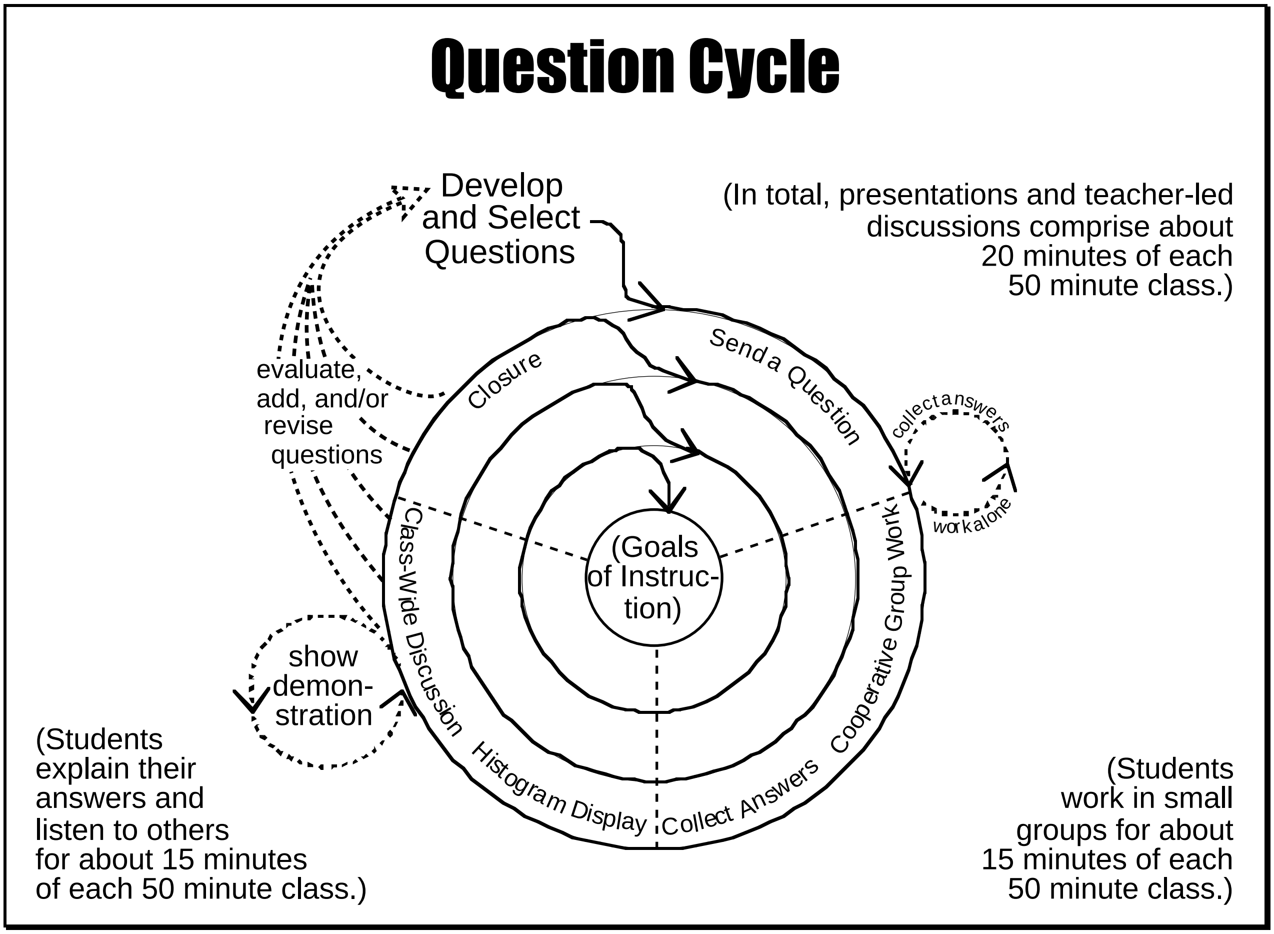

Figure 1: The structure of *Classtalk* instruction. Most class sessions can be broken down into cycles containing seven stages, beginning with Question Selection and Generation and ending with Closure. This *question cycle* is not a rigid format followed every class. Dashed lines represent examples of possible variations in the cycle.