Using Classroom Communication Systems: 
A Unique Technology-Based K-14 Outreach Program at an Engineering University

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Abstract: We describe a unique K-14 outreach program of Colorado School of Mines, a public engineering university. This program is centered on Classroom Communication Systems (a.k.a. student response systems), in which every student uses a handheld, wireless IR remote device to transmit a response to a question posed by the instructor. The responses are recorded and instantaneously compiled in a student-anonymous histogram for all to see. This technology facilitates the dual advantages of actively engaging students in constructivist learning and providing real-time formative assessment for both the instructor and the students.

Our successful use of this technology on campus is the foundation for an outreach program open to all Colorado educators, but targeting science and mathematics teachers. K-14 teachers come to campus to learn both technical and pedagogical aspects of using classroom communicators. They return to their own classrooms with all necessary equipment. Three weeks later, they return the equipment to campus and complete this professional development activity with shared reflection and summative assessment. They are eligible for subsequent checkout of the equipment. We discuss the mutual benefits this program provides to the teachers, their students, and the university.

Introduction
Colorado School of Mines, in Golden CO, is a public research university devoted to engineering and applied science. The Classroom Communicator Project was created when the Physics Department was honored in June 2001 with the CCHE (Colorado Commission on Higher Education) Program of Excellence Award. This prestigious recognition of the quality and robustness of the Engineering Physics program provided the original funding for dissemination of classroom communicator technology both on-campus and in outreach to the greater kindergarten through community college (K-14) educational community.

What is a classroom communication system?
Classroom communication system is a generic description for technology alternately known as a student response system, audience feedback system, or more commonly, “clickers.” When the teacher poses a multiple-choice question, every student in the classroom transmits a response using a handheld, wireless IR remote. The responses are collected by a receiver and recorded on a computer. The results, instantaneously compiled, are projected as a student-anonymous
histogram for all to see. The recorded responses of the students may be “graded,” at the discretion of the instructor.

There are several companies offering this technology on the market at competitive prices, including CPS by eInstruction, PRS by GTCO CalComp, H-ITT, and Qwizdom.

On the Colorado School of Mines (CSM) campus, classroom communication systems are used in all sections of the first two semesters of the calculus-based physics sequence, which is required of all students. Additionally, this technology is used in a wide variety of other classes including higher level physics, chemical engineering, chemistry, engineering, geology, and student development seminars (drug and alcohol abuse, stress management, healthy relationships, etc.). Our experiences with the classroom communication systems on campus serve as the foundation for our unique K-14 outreach program based on this technology.

**Pedagogical advantages of using classroom communication systems**

When teachers, students, educational theorists, and educational psychologists share their insights and data about the pedagogical benefits of using classroom communication systems, we notice two main trends in the advantages they report:

- *This technology actively engages every student in the classroom with the material being discussed; and*
- *This technology provides real-time feedback to both the instructor and the students about the level of student understanding.*

There is now a sizeable body of support for the constructivist theory of learning. Briefly summarized, the constructivist theory holds that one builds new knowledge and understanding based on previously learned concepts and facts, within the context of social interaction and agreement.

This “building” requires active, engaged students. Specific research studies and more anecdotal reports in science and mathematics classrooms show that some kind of involvement with course content during class time leads to gains in learning previously unseen when using more conventional approaches. The classroom communication technology encourages involvement of every student.

Furthermore, the constructivist theory underscores the importance of frequent formative assessment. Research indicates that enhancing the practice of frequent formative assessment with meaningful, individual feedback in a timely manner can produce significant and often substantial learning gains. Classroom communication systems provide both the teacher and students with real-time feedback to help gauge student comprehension. With this quick and simple way to assess the students’ prior and current knowledge, teachers can better devise effective instructional strategies. This technology also overcomes the obstacles of other forms of continuous assessment (lost class time, peer pressure, feedback not timely enough, clerical challenges, etc.), and hence is “a powerful mechanism for encouraging student self-awareness of their thinking and learning habits.”
Moreover, since this technology facilitates formative and summative assessment practices, it is clearly aligned with the ABET Criteria for accreditation of engineering programs\textsuperscript{17}. The real-time feedback that both the instructor and the students receive provides the data that drives subsequent instruction.

At the university level, the use of classroom communication systems is rapidly spreading. Surveys at Colorado School of Mines consistently show that around 80\% of our students think use of the clickers helped them learn and understand physics (unpublished data). This number agrees with reports from other schools, including University of Colorado at Boulder\textsuperscript{18}, University of Massachusetts\textsuperscript{15}, Harvard University\textsuperscript{11}, Christopher Newport University and the Ohio State University\textsuperscript{19}, Lancaster University\textsuperscript{20}, and to a certain extent, Eindhoven University of Technology in The Netherlands\textsuperscript{21}. These results seem independent of the size of the school, the socio-economic demographics of the students, the course subject or level, the instructor, etc.

**Goals of Outreach Program**
Future competitiveness of the United States is based on a robust engineering community. This in turn relies on intelligent and interested students entering the field. We hope to enhance and invigorate K-14 science and mathematics education throughout Colorado through the dissemination of and support of classroom communication technology. Also, we strive to strengthen the relationship between the university and area K-14 educators.

**Description of Outreach Program**
In overview of CSM’s outreach program, K-14 teachers come to campus to learn both technical and pedagogical aspects of using classroom communicators. They return to their own classrooms with a classroom communication system and all necessary associated equipment. Three weeks later, they bring the equipment back to campus and complete this professional development activity with shared reflection and summative assessment. After successful completion of the training, they are eligible for subsequent free checkout of the equipment.

The CSM Classroom Communicator outreach program is open to all Colorado educators, but our advertising strategy targets science and math teachers and they comprise the majority of our participants. The three-week class is offered six times per academic year and enrollment is limited to ten participants in each session.

Instruction throughout the training program intertwines pedagogical and technological aspects. The first Saturday of the training consists of an eight-hour workshop that builds on activities to develop a professional community, discussions of learning theory, and demonstrations of effective questioning strategies. In the early stages, participating teachers are given a chance to be on the “student end” of the clickers as a variety of questions and activities demonstrate some of the capabilities of the classroom communication system.

Building on this foundation, every participant then receives a laptop pre-loaded with the necessary software. Using the teaching materials they have brought with them to the training, teachers begin creating, modifying, or transferring questions they can use the following week in their classrooms. They become thoroughly familiar with the features of the software, including:
how to create question banks, how to operate the classroom communication system, how to electronically link all questions to state and district standards, how to generate reports of class and individual performance (overall and by particular standards), how to use this equipment in conjunction with existing student data files and electronic gradebooks, how to assemble the classroom communication system for classroom use, and special applications.

Once the teachers have mastered these basics of the technology, they are very receptive to addressing some of the associated pedagogical considerations. Particular emphasis is placed on how teachers can effectively respond to the real-time feedback this technology provides.

Finally, participating teachers each receive an LCD projector and learn how to use it correctly. Security cables for the computers and projectors are provided, as well as carrying cases, surge protectors, external floppy drives, flash drives, extension cords, etc. In short, when the participants depart from campus on Saturday afternoon, each with $3000- $5000 worth of equipment, they have firm pedagogical and technological foundations and are ready to use the classroom communication system in their own classroom on Monday morning.

For the next three weeks, the project coordinator is available to provide telephone and e-mail support for the participants. Sometimes this involves trouble-shooting problems that arise, but just as often it is more focused on sharing the participants’ enthusiasm about having this technology in their classroom and encouraging them to explore effective applications. Each participant submits weekly e-journals addressing a variety of assigned topics regarding their experiences.

At the end of three weeks, the participants return to campus for a four-hour workshop. During this meeting, they relinquish all the equipment they have borrowed and reflect on their experiences with it. Again, there is a meshing of pedagogical and technological considerations. By sharing some of the questions they have created, they give the other participants a glimpse at how they put the technology to use. By this point, there is usually a sense within this professional learning community that they can safely exchange constructive comments about their experiences. The remainder of the workshop is devoted to looking at various classroom communication systems on the market and comparing their advantages and disadvantages.

At the successful conclusion of the outreach training session, each participant receives one semester hour of graduate credit, applicable to renewing their teaching credential. For the participants, the issue of sustainability (continued use of this technology in their classrooms) is addressed in two ways. They are eligible for subsequent checking out of any of the four types of classroom communication systems (CPS, H-ITT, PRS, and Qwizdom) and all associated equipment. Also, our project supports the participants if they choose to develop proposals seeking funding to obtain their own equipment. A surprising number of participants have purchased classroom communication systems for their own classrooms, through small grants or PTA, building, district, or external funding. All participants are encouraged to contribute to our project the questions they have entered into the communicator software. Thus, we have established a ready-made question bank that can be used by anyone who contributes to it.

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Some successful uses of this technology by teachers in the outreach program

Participating K-14 teachers that complete the outreach training program have all been able to use this technology successfully in their classrooms. They have explored various applications to see what works best in their particular teaching situations, but we consistently observe these effective uses of the classroom communication systems:

• To quickly assess what students already know, so that class time can be used more effectively by building on that.
• To determine the students’ intuitive understanding, so that the teachers knows how to approach an upcoming topic and how difficult it may be for the students.
• To measure comprehension of a homework assignment, to know at the beginning of the period what topics are still not mastered.
• To survey opinions in a peer-anonymous or totally anonymous manner.
• To engage students in a “convince your neighbor” exercise\textsuperscript{11}, then enter answers either independently or as a team.
• To review topics, and instantly see those areas still troubling your students.
• To pique students’ interest by asking them to predict a result.
• To reinforce learning, by presenting a question that asks students to apply a new concept.
• To focus students’ attention, by opening a class period with a question that reviews concepts covered in the previous session.
• To re-focus students’ attention, by asking them a question about a topic just covered.
• To help students become more familiar with multiple choice questions in the subject area and develop skills in analytic thinking applicable to standardized tests.

Results: Benefits of the outreach program to participating K-14 teachers

For the majority of participants, this professional development activity is a passageway for using classroom communication systems in their classrooms. As mentioned, completion of the training class yields one semester credit hour of graduate-level credit appropriate for recertification, as well as future checkout privileges for the equipment. On all subsequent checkouts, participants have their choice of any of the four classroom communicator systems we have: CPS, H-ITT, PRS, and Qwizdom (see above).

Many teachers report that they have been under continual pressure by their administrations to use technology in their classrooms, and yet have previously had difficulty doing that in a pedagogically meaningful way. This program, the theoretical foundation it provides, the technology it puts in their hands, and the support the program offers, together have earned the participants’ enthusiastic endorsement of this as an effective pathway for the use of technology.

As a measure of the effectiveness of the training, every participating teacher has reported that they were able to successfully use the technology in their own classroom. Additionally, exit surveys are administered for the Teacher Enhancement Office at the conclusion of each training session. Compiling results from the 14 training sessions presented to date, 100% of participating teachers have agreed with these statements:
“Activities presented will be useful to me.”
“I would recommend this course to others.”
Additional comments from the participating teachers (via exit surveys and class journals) reveal the benefits they perceive:

- I have been borrowing the "clickers" from CSM to use in my math classroom for almost two years. I have used them in honors classes, remedial classes and everything in between. When I first tried them, I knew the students would enjoy a change of pace but I was frankly surprised by the intensity of their reactions. The student response was so positive, and I felt they were more engaged than almost anytime I had seen them. Initially I had wondered if the students' interest in the clickers would wane over time, but that doesn't seem to be the case. In fact, when I bring in the laptop computer for other purposes they express disappointment that it is not for the clickers. Diagnostically they are a terrific tool for the teacher. I can see immediately whether the students understand a certain concept. By their incorrect answer choices I can even address their specific misunderstandings. I am thrilled to add the "clickers" to my teaching bag of tools and I see myself using them even more in the future as I learn more ways to use them. *H.S. math teacher, JeffCo Public Schools*

- I truly think that this technology holds the potential to revolutionize the way we do business in the classroom on a daily basis. *H.S. science department co-chair, Englewood Public Schools*

- The response from our students was overwhelmingly positive. Our students consistently cited their increased attention in class and improved learning due to the remote system. CSM’s program (offers) an extremely effective instructional strategy to improve science education. *H.S. science and technology and physics teacher, Cherry Creek Public Schools*

- The class camaraderie [when using this technology] is amazing….There is a lot of cooperative learning. *Middle school physical science teacher, JeffCo Public Schools*

- I have found that 3 short weeks with the clickers have changed the way I teach! *H.S. science teacher, Boulder Valley Public Schools*

- This was …the most value I have got(ten) for any one-credit professional development seminar I’ve attended (and I attend a lot!) because…it is a very fulfilling, interesting, and well-run program. *Elementary foreign language teacher, Academy District 20 Public Schools*

- I noticed that the students that normally are non-participating were involved and actively engaged. That was exciting to see. *Middle school science and language arts teacher, Adams 50 Schools*

- (In our bullyproofing sessions,) the clickers opened the door to some great problem solving that otherwise I do not believe would have occurred!!! *Middle school guidance counselor, JeffCo Public Schools*
• (This technology) gave many of my students the confidence they needed to ask additional questions later. *H.S. chemistry teacher, JeffCo Public Schools*

• I teach a variety of technology-based courses to adjudicated females ages 12 through 20 in a maximum security setting….The end result was that I had, for the first time ever, 100% participation! The prospect and potential for these kinds of systems is clearly enormous. *Vocational instructor, Metro Academy Girls’ View, Denver*

• In the past week I have had visits from other teachers, our technologist, the principal, and some student teachers. All are interested in this technology and I am a hero for bringing it to our school. *H.S. biology teacher, JeffCo Public Schools*

• In my earth science classes today, we went through about seven questions on the layers of the atmosphere. The students had made a graph of the layers, and we had discussed them. I thought that the clickers would be a great way to check for understanding, but I expected the students to get all the questions right because I thought they understood the concepts. Boy, was I wrong! Then, we had a great discussion about the layers of the atmosphere, because the students realized they didn’t understand. *H.S. earth science teacher, JeffCo Public Schools*

• One student who really benefits from the clickers is a girl who is wheelchair-bound and has practically no physical control at all (she can NOT write at all, and struggled to grasp the Skittles she’d won as a prize), but she was thrilled with the clickers, as was her para-professional aide, because (the student) could do the entire quiz by herself. Really, she was on “equal footing” with her peers on this one. *Elementary foreign language teacher, Academy District 20 Public Schools*

• I’m having a great time with these gadgets. I have rediscovered my enthusiasm for teaching the same old stuff, because I’m using a method that’s new, fun, and really works! *H.S. science teacher, Buena Vista Public Schools*

The sense of community shared by the professional learning group formed by the participants is evident in the development of the question bank. As described above, all participants are invited to contribute the questions they have authored and entered into the CPS software. Other teachers who contribute can then use these questions in their own classes, saving considerable effort. Over 90% of participants have contributed to the shared question bank. This is an ongoing, ever-growing resource for teachers just entering the program as well as those who continue to borrow the equipment and those who have obtained their own equipment.

Two of the training sessions offered to date have targeted teachers of particular subject areas: one session was exclusively chemistry teachers, and another was entirely physics teachers. These sessions were particularly beneficial to participants, since they could immediately share all

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materials they created. Each of these sessions also included subject-specific content enrichment presentations by CSM faculty, which exit surveys indicate the participants found very beneficial.

**Results: Benefits of the outreach program to K-14 students**

In the 2004 calendar year, we have had 106 instances of equipment checkouts, with an average duration of 3 weeks each. Considering that most secondary teachers have total average rosters of at least 125 students each, we feel that in terms of sheer numbers of students impacted, this program has been significant.

Since students who use this technology in their classes are engaged with their learning and receiving frequent real-time feedback about their understanding, it is hoped that this is enhancing their learning and increasing their interest in the subject matter, particularly science and mathematics. However, it is not within the scope of our project to measure the effects of this technology on the actual learning of students in these classrooms.

Teachers participating in our outreach training program administer surveys to their students to help assess the benefits of using this technology in K-14 classrooms. Here are some of those survey results:

- When (my) students were polled about what they thought the educational benefits were, here is what they said: “I like the fact that I can see immediately if my answer is correct and especially when the system is used as a review, can clear up misconceptions right away.” Every one of my 115 students polled agreed with this statement. *biology teacher, JeffCo Public Schools*

- When I brought out the clickers, the students REALLY responded well….They all were able to see their weaknesses and were better positioned to decide how to most productively use their class time. All the students were engaged and participating, a situation that does not often happen. My survey results:
  - Did you think that the use of the clickers helped you concentrate better on what was going on in class?
    - a. Yes 92%
    - b. No 8%
  - Did the use of the clickers help you recognize things you hadn’t learned well enough, that you need to review?
    - a. Yes 91%
    - b. No 9%
  *Science teacher, Englewood Public Schools*

- My students are a combination of coming from very poor families to the lower side of middle class working families…Out of 6 classes and approximately 180 students, I didn’t receive one negative comment. Ten students wanted to start a fund-raising drive to buy this system (for our school). *Middle school science teacher, Aurora Public Schools*

- I remembered more information through using this system. *JeffCo Public Schools H.S. student*
• 96% of my students felt the system helped them understand material better, and 93% felt the system helped them do better on the unit tests (test scores did improve).  
  H.S. science teacher, St. Vrain Public Schools

• Surveys taken in our middle school science classes indicate that an overwhelming majority of students (95%) enjoy using the communication system, believing that it helps them to focus.  
  Middle school science dept. chair, Littleton Public Schools

• This was an amazing way of learning. It used new technology and we still learned.  
  JeffCo Public Schools H.S. student

• I liked this because…when you got an answer wrong, no one had to know it was you.  
  JeffCo Public Schools H.S. student

• I thought the clickers were a great learning experience. They were a great way to get us to all interact with each other.  
  JeffCo Public Schools H.S. student

• The “clickers” (made chemistry) extremely lucid. What I like most about them is the fact that they…eliminate initial misunderstanding of the subject.  
  Aurora Public Schools H.S. student

• I began to understand class and the work more with the clickers.  
  Aurora Public Schools H.S. student

• The clickers were very fun and a great way to do our work. Thank you for your courtesy and letting us use them. I had a lot of fun and actually looked forward to biology because of the clickers! Thanx again.  
  Aurora Public Schools H.S. student

Additional benefits to students that we have observed include the students having an opportunity to see their teachers fluently using technology, students gaining new insights into strategies for answering objective questions, and an increase in the social component of learning.

**Results: Benefits of the outreach program to the university**
The K-14 outreach program has been beneficial to Colorado School of Mines in several critical aspects. Since the training sessions are held on campus, teachers’ attendance increases their awareness of Colorado School of Mines and some of what it has to offer. Furthermore, through the project coordinator, they also have a friendly resource person on campus. In many cases, this has facilitated further communication between CSM and the K-14 community. Other faculty members seeking to establish their own outreach efforts have benefited from these contacts and strengthened ties.
Among other benefits of this improved communication is the usefulness of this program in recruiting new students. One high school chemistry teacher wrote, “(My bringing this technology into my classroom) initiated some discussion about what type of school Mines is, where it is and how to apply and be accepted, etc. I found this to be a very hopeful and exciting conversation…” K-14 educators are influential in increasing the awareness of their students about post-secondary educational opportunities and in guiding the choices their students make. In some of the training sessions, participating teachers have been asked to invite their promising students to come to campus with them and learn more about the university directly.

In addition to serving as a recruiting tool, we feel that our program is also contributing to the academic strength of the pool of recruited students. If the prospective students are better prepared in science and mathematics through the use of the classroom communication systems in the K-14 education, it is a win/win situation for both the students and the university.

The outreach project has also strengthened ties between Colorado School of Mines and other components of our community. For example, the training division chief of the City of Golden Fire Department, the Colorado state judicial educator (who works with judges, attorneys, and citizens), and the Colorado Department of Public Health and Environment’s environmental compliance officer have enrolled in our outreach training program.

Conclusions
We present one component of our classroom communicator project as an effective K-14 outreach tool for an engineering university. Before beginning this novel outreach program, we gained practical experience with this technology on-campus. In this paper, we have also briefly described some of the theoretical underpinnings for the use of this technology, drawn primarily from the constructivist theory of learning. Based on this theoretical foundation, supporting research and anecdotal evidence in the literature, and our own experiences, we believe there are two primary advantages of using this technology. These advantages are consistent in both K-14 and undergraduate engineering educational settings. First, through the use of a classroom communication system, instructors can actively engage every student in their learning. Secondly, the classroom communication system provides real-time feedback about student learning to both the teacher and the students. This allows class time to be used more effectively and sharpens the students’ metacognition. This facilitation of formative and summative assessment practices is clearly aligned with the ABET Criteria for accreditation.

Although this technology is readily available at reasonable prices on the market, many K-14 instructors are either not aware of it, do not know how to use it effectively, and/or do not have access to it in their classroom. The outreach program at Colorado School of Mines addresses all three of these limitations. In this paper, we have described the details of the design and delivery of that program.

The outreach program has been very enthusiastically received by both K-14 teachers and their students. As evidence, we provide quotes, student survey results, teacher exit survey results, and records of subsequent equipment checkouts.
By disseminating and facilitating the use of this technology in science and mathematics classrooms throughout Colorado, we believe the outreach program is improving the quality of our potential applicant pool by enhancing and invigorating instruction occurring in K-14 classrooms. Simultaneously, the outreach program increases public awareness of the university, serves as an effective recruiting tool, and strengthens ties between the university and the K-14 community.

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Bibliographic information
1. for additional product information about CPS, please refer to the eInstruction website at http://www.einstruction.com.
2. for additional product information about PRS, please refer to the GTCO CalComp Inc. website at http://www.gtcocalcomp.com.
4. for additional product information about Qwizdom, please refer to the Qwizdom, Inc. website at http://qwizdom.com.


Biographical Information

SUSAN E. KOWALSKI (M.B.S., University of Colorado, Boulder) has been project coordinator for CSM’s Classroom Communicator Project since its inception three years ago. Her teaching experiences at the secondary and community college levels have guided the design and delivery of the on-campus and outreach components of the project.

FRANK V. KOWALSKI (Ph.D., Stanford University) is a professor of physics at CSM. As a strong proponent of using classroom communicators to improve physics instruction, he uses this technology on a regular basis in the courses he teaches and encourages other teachers (both on-campus and in the K-14 outreach program) to explore the possibilities this technology facilitates.

ADAM P. KOWALSKI has been instrumental in the design and delivery of the technological component of this outreach program. In partial fulfillment of requirements for an International Baccalaureate Diploma, he has made extensive and original contributions. Recently, he left the project to attend Lewis & Clark College, Portland, OR.