Using Low-Tech Interactions in the Chemistry Classroom To Engage Students in Active Learning

by Michael P. Shaver
Department of Chemistry, University of Prince Edward Island, Charlottetown, PE, C1A 4P3 Canada
mshaver@upei.ca

Active learning methods provide an alternative approach to curriculum delivery, focusing the responsibility of learning on the learners. Increasing student engagement in the classroom is becoming an essential element to reaching students who are often equipped with ever-increasing technological distractions and whose attention spans seem to be ever-decreasing *(1, 2)*. Bonwell and Ellison championed an active learning approach to instruction and suggested learners who work together, discuss material, and engage in activities show similar content mastery to a lecture format, with superior retention of information and critical thinking skills *(3)*. It is important to balance experiential learning, such as completing assignments outside of class time, with appropriate guidance, as unguided situations can produce learners with lower levels of understanding *(4)*. Active learning has become an essential tool for improving chemistry education, including the introduction of student-focused learning activities in the classroom and laboratory *(5)*, the development of interactive anonymous quizzes *(6, 7)*, and the emergence of electronic-response systems in the classroom *(8)*.

Electronic-response systems, or clickers, have been found to provide exceptional utility in the classroom *(8)*. They enable instructors to receive instantaneous feedback during class from the entire group of students, not just the select few who voluntarily interact. Associated programs can tabulate results as a histogram, providing a nonthreatening opportunity for student participation and active learning. The results from a particular question can also be used to initiate discussion, allow an instructor to correct misconceptions, and provide an opportunity for think—pair—share activities *(9)*; learners can answer the question, discuss their answer with their peers, and post their revised opinions. Chemists have been quite creative in their use of clicker technology, even applying them elegantly to open-ended synthesis questions *(10)* and curved arrow notation questions *(11)*.

However, these electronic-response systems are not universal tools for the chemistry classroom, and have been met with strong demands for justification of their costs. Bugega insists that the use of clickers is both driven and promoted by profit-making organizations and that incorporation of this technology comes at a significant price *(12)*. This price might be absorbed by an overstretched departmental or faculty budget; more often than not, however, the cost is passed onto students who have not been consulted on the technology costs or effectiveness. Proponents of these systems argue that Bugega fails to consider any of the research looking into the impact of teaching with clickers on student learning *(13)*. The value of these systems is especially apparent if a clicker system is adopted campus-wide, where the per-course cost of this technology is significantly lowered.

This article describes two active learning activities that do not require the purchase of electronic-response systems and allow for similar pedagogical benefits in classroom settings that are both "smart" (equipped with the necessary projectors and technology interfaces), and "traditional" (equipped with chalkboards or whiteboards). This commentary is not meant to serve as a discourse on the pros and cons of electronic-response systems; rather, a need remains for individuals and institutions who do not have access to this technology to maintain an engaged classroom and improve student education.

Built-In Clickers: Our Hands

In-class, low-tech alternatives to clickers have been used extensively in the past, from colored popsicle sticks to individual student slates to the simplest of all: a student's own thumbs. Students can answer simple "yes" or "no", and "true" or "false" questions by simply showing "thumbs up" (positive) or "thumbs down" (negative). In the first class of a second-year inorganic chemistry course focused on coordination chemistry, students are posed with a nonthreatening question unrelated to the course material. When asked "Are you in your second-year at UPEI?" or "Do your shoes have laces?", the students are encouraged to respond with their thumbs. This initiates camaraderie with the students and eases them into answering course-related questions. These nonthreatening questions can be used throughout the semester to maintain a relaxed classroom atmosphere.

Signaling a thumb up and a thumb down provides two selections that students can make, and this simple trick can be expanded to allow for more complex questions to be answered. A sideways thumb supplements these selections, indicating that the student is unsure of the answer. This is an essential addition, as it ensures that every student has an answer. Questions progressively increase in complexity in which students can continue to answer with their thumbs and fingers: "How many valence electrons does nitrogen have?" (five fingers up!) to "What is the coordination number for $[Co(OH_2)_6]^{2+}$?" (six fingers up!) to "What isomer of $[Co(en)_3]^{2+}$ is shown on the screen?" (delta or lambda symbols!). These additional selections can be added with a student's fingers to answer multiple-choice questions and can be extended to any number of gestures to provide the class with needed levity. It is suggested to students that they can keep their answers anonymous by holding their thumbs close to their chests, which is essential to keeping students answering honestly instead of voting with the majority to save face.

While no graphical representations are immediately available, instructors can use their observational skills to assess the student responses. Just as with electronic response systems, students are actively engaged during the entire class period,

10.1021/ed900017j Published on Web 08/30/2010

instructors can gauge their level of understanding of the material being presented and provide prompt feedback to student questions. Beneficially, students do not need to remember to bring their clickers, flash cards, or popsicle sticks; one cannot forget to bring one's thumbs to class. While there are significant logistical challenges in using these techniques effectively in large classes of >100 students, smaller classes will benefit from the incorporation of this simple, free, pedagogical tool. Thumbs provide an instructor with a quick, effective method to interact with his or her students in any setting.

Additionally, this technique actually provides information that is unavailable with existing electronic response technology. First, the instructor receives real-time information about not only how many people are participating, but also which specific students are nonparticipants. While electronic response systems provide aggregate participation numbers, instructors would have to examine individual clicker codes following class to find these individuals. An instructor can immediately tell that someone is not participating, remind the class of the "thumb sideways" option, and wait for a response. While this technique does not have the real-time anonymity and induced compliance, high participation can be achieved by due-diligence on the part of the instructor, even in the absence of assigning a grade to this compliance. For a habitual nonparticipant, the instructor can approach the student directly after class to discuss the issue. I have found that this open approach has resulted in 100% participation in these activities, exploiting student guilt to induce their participation. Second, the instructor receives real-time information about whether regional trends in understanding exist in a classroom setting, situations where a localized subsection of the students have a challenge grasping a concept. I have noticed that groups of students who are struggling in the course often sit close to each other, often interacting little with the rest of the classroom. Noticing whether a certain area of the classroom is showing a deficiency or misconception in their understanding allows the instructor to focus their discussion with these students, identify the issue, and correct it immediately.

The "thumbs" idea is used throughout all of my courses, which include second-, third-, and fourth-year inorganic and science communication courses. Here, I highlight the application of this technique to a second-year coordination chemistry course in a lecture on Lewis acids and Lewis bases where we discuss hard–soft acid–base theory. Viewing 20 presentation slides complements traditional whiteboard lecturing; the slides are interspersed with questions, including:

1. Draw a LAB bond between trimethyl indium (Me_3In) and triethyl amine (NEt_3), remembering the bond forms between the N and In atoms and is represented by an arrow. Is the arrow pointing from In to N (thumb up) or N to In (thumb down)?
2. Would Ag^+ form a stronger bond with trimethyl amine (NMe_3, thumb up) or trimethyl phosphine (PMe_3, thumb down)?
3. For the reaction: $Nb_2S_5 + 5\ HgO \rightarrow Nb_2O_5 + 5\ HgS$, which side of the equilibrium is favored? The left (thumb up) or the right (thumb down)?
4. Remember from a previous lecture that ambidentate ligands can attach to the central atom in two places, but not both. Which side of the equilibrium would be favored in this reaction: $[(NH_3)_5Fe(NCS)]^+ \rightarrow [(NH_3)_5Fe(SCN)]^+$? The left (thumb up) or the right (thumb down)?

For each of these questions, students are encouraged to use a sideways thumb to express confusion or a lack of understanding. Participation for all questions was 100%, with no coaxing of the students required. Results for Question 1 ($N = 45$ responses) were as follows: thumb up, 18% (8 responses); thumb down, 76% (35 responses); thumb mid, 4% (two responses). Recognizing that some students did not answer the question correctly, the instructor allowed time for students to draw the Lewis structures of the compounds in questions and embrace the question as a learning opportunity. By walking through the first examples slowly, answers on subsequent questions improved. Question 2 ($N = 45$ responses) results indicated that 41 students (91%) answered correctly (thumb down), while 4 students (9%) suggested they did not know. Question 3 ($N = 45$ responses) results indicated that all students (100%) answered the question correctly (thumb down). Question 4 proved more of a challenge, as students were asked to bring a concept from earlier in the course and relate it to the current lesson. Of the 45 responses, 30 students correctly suggested the right side of the equilibrium was favored, while 15 students answered incorrectly or "I don't know". This provided an opportunity for students to work together to solve this problem. Students were invited to take a few moments to talk to a partner, trying to come to a consensus answer. A second polling showed the effect of this brief student engagement, with 100% of students answering the question correctly.

As the students build expertise in writing Lewis acid–base reactions, recognizing hard, borderline, and soft acids and bases, and applying these ideas to equilibria and ambidentate ligands, the students are actively engaged throughout the lecture and I have immediate feedback on their level of understanding. This topic is presented early in the course, so the questions are relatively straightforward and can be answered just with the thumbs.

Cue Cards and Worked Examples

As detractors to clicker technology rightly point out, there are many instances where student comprehension cannot be gauged by simplistic questions and where learning opportunities are better framed in worked examples of problems *(14)*. This same problem arises with low-tech polling techniques. As an example, students in the aforementioned second-year coordination chemistry course need to master the naming of inorganic coordination compounds. As the students were being taught this topic, they were presented with a multiple-choice question with three distracters. Having the four possible answers in front of them, 98% of the students (44/45) correctly determined the compound's name. The next class, however, students were provided an open-ended question to determine a similar compound's name. Without the guiding answers, student performance dropped considerably (28/45, 62%). Student comprehension and the students' ability to name compounds independently were not represented by their thumb responses. More worked examples were required to improve student understanding, while maintaining the high level of student engagement offered by student polling.

Worked examples have a rich history in teaching and learning chemistry, and are a highlight of most chemistry textbooks *(15)*. In a worked example, students are shown the complete solution to a typical problem. Traditionally, these problems can be worked through by the instructor or with the assistance of students from the class. Invariably, with time for only selected examples to be shown, the keen and energetic students will dominate these participation opportunities, allowing other students to become invisible in the classroom. How can we engage students as participants in worked examples while ensuring that all students have a chance to participate?

At the end of a class period in which the instructor has worked through an example of a new task or topic, cue cards are handed out randomly to the class. Each student must pick one card, eliminating the "volunteer" aspect that often afflicts student participation. On several of these cards, compounds or questions are given, with one card for each example the instructor wishes to work through the next class. On the remainder of cards are written the words "Get Out of Jail Free" or "Free At Last!". Students are encouraged to see if they are "lucky" and choose a card from the front of the room. This amounts to choosing volunteers at random to assist with worked examples, without the connotation that anyone is singled out. Students then have the opportunity to prepare for the next class, where they work through the problem on their card with the instructor's assistance. Office hours are reserved before the next class to assist any students that are nervous.

Having students prepare the answers to these worked examples allows for many careless errors to be addressed outside the classroom, but allows for common mistakes or misconceptions to be highlighted naturally in the classroom *(16)*. Careless errors are those that show that the student is capable of mastering the subject but has provided an incorrect answer including spelling, mathematical, and recall errors. Misconceptions are those errors based in a lack of conceptual understanding, an incorrect assumption, or a presumption. Students often present incorrect answers to the class, and the instructor can directly address these with constructive criticism. In a nonthreatening way, students see that others can make mistakes and more importantly that these mistakes are easily corrected. Students are more engaged as both participants and learners, as they are being taught by multiple voices, including the instructor and their peers. Often, examples of increasing complexity are presented and provide opportunities for the instructor to introduce more layers to the topic in question.

In the aforementioned second-year inorganic course, this technique is used to build students' abilities to master coordination chemistry. Cue card worked examples are used for (i) drawing coordination compounds; (ii) naming coordination compounds; (iii) determining oxidation state, and d-electron and valence electron counts; and (iv) determining the point group of a compound. In each of these activities, 12 examples of increasing complexity are given and students have an approximately 25% chance of choosing a cue card with an example. Turning the students into teachers to supplement, not supplant, the instructor's role has proven highly rewarding. Additionally, while student were visibly excited to receive a "Get Out of Jail Free" card on the first round, by the end of the course, this emotion had transformed into disappointment: Students recognized the value of the activity and wanted to participate!

This technique has been particularly useful in teaching molecular symmetry, providing students opportunity to practice discovery learning. In presenting students with cards inscribed with a compound or an object, students are tasked with building or finding a model of the structure and investigating its symmetry based on some rudimentary knowledge of planes, rotations, and inversions. Common student misconceptions were highlighted, especially focusing on the difference between vertical (σ_v) and horizontal (σ_h) mirror planes, the presence of multiple higher-order axes ($\geq C_3$), and the presence and number of dihedral C_2 axes related to D_n point groups. Instructor responses are maintained in an overtly positive tone, exemplifying what the student did correctly, showing where misconceptions or errors were made, and highlighting that small changes to student's thinking would lead them to a correct answer.

Outcomes and Summary

Student response to both thumb and cue card active learning exercises has been overwhelmingly positive. These two techniques are consistently highlighted in course teaching evaluations as transformative for student success. On the recommendation of students, instructors in synthetic organic and spectroscopy courses are applying these techniques. Students cited the quick and easy approach to thumbs for engagement as very beneficial and, for those students aware of the technology from other courses, appreciated that they did not have to purchase a personal electronic-response system. They appreciated the number of examples and the different approaches students would take when working through their problems in the cue card exercises.

These student response surveys were supplemented by a perception survey modeled after similar surveys used in supporting the pedagogical benefits of clicker technology *(17)*. Table 1 summarizes the results from two sections (91 responses) of the second-year inorganic chemistry course described above.

The results in Table 1 show that the majority of students agree or strongly agree with each of the provided statements, with results in the range of 74−91%. Students especially indicated the benefit of cue card work; 60% of students strongly agreeing that cue card work improved their understanding of the course material, while 68% strongly agreed with their future use in the course. While the statistical significance of this survey is minimal without appropriate control groups, and a perception-based survey does not measure the impact of pedagogical changes on student examination results, it is clear that the students view these active learning strategies as important tools in their education.

In an effort to garner a quantitative impact of the use of cue cards, students were given two short assignments of five molecules for which they had to identify the point group, rotational axes, and mirror planes. One assignment was given directly after the material had been taught and students had been shown several examples by the instructor. The average grade on this assignment was 65%. Students were then engaged with cue card exercises and educated by their peers with instructor support. A new assignment of five molecules yielded an average grade of 88%, a dramatic improvement of 23% over the previous assignment. Students commented on how the second assignment seemed "easier" now that they had observed the errors of others.

Examples provided focus on coordination chemistry; however, the teaching tools can be applied to a much broader range of scientific disciplines. Interacting with students by incorporating quick thumb polls and involved cue cards allows for a teacher to improve student understanding, increase student engagement, and keep students focused on learning.

Table 1. Perception Survey on the Use of Thumbs and Cue Cards

Statement for Student Response	Responses by Category (N = 91)[a]				
	SD	D	N	A	SA
Participation with thumbs improved my understanding of the subject content.	1	1	12	56	21
Participation with thumbs increased my interaction with the instructor and other students.	0	3	5	23	60
I would recommend using thumbs again in this course.	1	1	5	41	44
Participation with cue cards improved my understanding of the subject content.	1	0	7	28	55
Participation with cue cards increased my interaction with the instructor and other students.	0	0	24	13	54
I would recommend using cue cards again in this course.	2	0	16	11	62

[a] SD = Strongly Disagree, D = Disagree, N = Neutral, A = Agree, SA = Strongly Agree.

In conclusion, thumbs are free, low-tech alternatives to electronic-response systems in classroom settings, especially when classrooms are not equipped with the appropriate smart technology and consist of medium to small groups. While thumbs should not be thought of as a replacement to clicker technology, they provide an immediately accessible alternative for instructors and departments. This technique provides a simple way for instructors to engage their students and receive real-time feedback on their understanding. This approach can be complemented in the classroom by student-driven worked examples based on a random assignment of these examples through using cue cards. While these techniques are not necessarily influential because of their novel or innovative approach, it is hoped that this paper introduces and reminds educators of the importance of simple methods of student engagement. It is also hoped that instructors outside of inorganic chemistry courses will embrace these techniques, expanding their use and impact to improve students' chemistry education.

Literature Cited

1. Postman, N. *Amusing Ourselves to Death: Public Discourse in the Age of Show Business*; Penguin Books: Washington, DC, 1985.
2. Christakis, D. A.; Zimmerman, F. J.; DiGiuseppe, D. L.; McCarty, C. A. *Pediatrics* **2004**, *113*, 708–713.
3. Bonwell, C.; Eison, J. *Active Learning: Creating Excitement in the Classroom*, AEHE-ERIC Higher Education Report No. 1.; Jossey-Bass: Washington, DC, 1991.
4. Kirschner, P. A.; Sweller, J.; Clark, R. E. *Educ. Psychologist* **2006**, *41*, 75–86.
5. Spencer, J. N. *J. Chem. Educ.* **1999**, *76*, 566–569.
6. Holme, T. *J. Chem. Educ.* **1998**, *75*, 574–576.
7. Wagner, B. D. *J. Chem. Educ.* **2009**, *86*, 1300–1303.
8. Barnett, J. *Australas. J. Educ. Technol.* **2006**, *22*, 474–494.
9. Bruff, D. *Teaching with Classroom Response Systems: Creative Active Learning Environments*; Jossey-Bass: Washington, DC, 2009.
10. Sauers, A. L.; Morrison, R. W. Abstracts of Papers, 233rd National Meeting of the American Chemical Society, Chicago, IL, Mar 25−29, 2007; American Chemical Society: Washington, DC, 2007; 838-CHED.
11. Ruder, S. M.; Straumanis, A. R. *J. Chem. Educ.* **2009**, *86*, 1392–1396.
12. Bugeja, M. Classroom Clickers and the Cost of Technology. *The Chronicle of Higher Education* , Dec. 5, 2008.
13. Fies, C.; Marshall, J. *J. Sci. Educ. Technol.* **2006**, *15*, 101–109.
14. Brooks, D. W.; Shell, D. F. *J. Sci. Educ. Technol.* **2006**, *15*, 17–30.
15. Hornby, M.; Peach, J. *Foundations of Organic Chemistry: Worked Examples*, Oxford Chemistry Primer No. 87; Oxford University Press: New York, 2001.
16. Unlu, A. *J. Math. Psych.* **2006**, *50*, 309–328.
17. Martyn, M. *Educause Q.* **2007**, *30* (2), 71–74.