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Optimizing the Use of Personal Response Devices (Clickers) in Large-Enrollment Introductory Courses

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Electronic or personal student response systems, often referred to as “clickers”, are small handheld devices with which students may remotely, mutely—and potentially hidden from the eyes of their instructor and peers—respond to questions that are posed during lecture *(1)*. Wireless clicker systems are often limited to answering true-false and multiple-choice questions, although some systems allow responses with quantitative numeric entries.[1] Other software products[2] can receive responses in full alphanumeric code from students’ laptop computers, pocket PCs, or handheld devices. Numerous pilot projects and pedagogical studies currently underway at institutions of higher education are designed to test different hardware and software systems and analyze the potential benefits and shortfalls of clickers with respect to teaching and learning success.

While many studies are still in progress, especially those seeking to quantify learning outcomes, clicker systems have already been permanently installed in numerous college and university classrooms, particularly for use in large-enrollment first- and second-year science courses. Evidently, instructors are encouraged by their own or their colleagues’ evaluation of the technology so that they are willing to try or stick with this new way of interacting with students in the classroom. As the devices, hardware, and software have become less expensive, high school instructors are also experimenting with clickers.[3] Teaching research studies *(2, 3)* and personal anecdotes, many of which are presented on Web pages, praise the successful contribution of clickers for enhancing the students’ engagement in large-enrollment courses *(4)* and the positive impact clickers may have on final course grades *(5)*. A closer look at these studies indicates that the use of clickers particularly helps students with low grades to maintain or regain their interest in the subject matter. A recent literature review article is available *(6)* focusing on reports of clickers in educational settings.

Taxonomy of Clicker Use

Instructors who use clickers in their classrooms usually observe different levels of benefits and achievements. These typically range from quickly taking attendance or probing participation to the multifaceted benefits teachers and learners gain from immediate and quantitative feedback. Clickers are also praised as a tool to encourage cooperative learning and peer instruction even in traditional, large lecture halls. Hence, to fully understand the immense potential of teaching and learning with clickers, a better classification of clicker tasks is much needed. The classification presented here illustrates six basic categories, each with suitable examples from the author’s general chemistry courses. The categories are intended to assist both novices and experienced instructors in realizing the full potential of current clicker technology, from simple attendance checks to promoting critical thinking and in-depth learning.

It is worthwhile to distinguish between two major categories for which clickers are generally used in the classroom. The first enables instructors to determine students’ current status or disposition. This “*I am*” category allows students to electronically articulate: “*I am here*”, “*I am prepared*”, or “*I am interested*”. The second one, the “*I do*” category, probes learning progress. Correct responses to clicker questions of this category require students to actively engage in the subject matter. Put another way, correct answers indicate progress in students’ learning, and relate to the electronic statements: “*I learn*”, “*I understand*”, or “*I apply*”.

“I Am” Category of Clicker Use

“Click”—I Am Here

Experience shows that taking and honoring attendance reduces the number of students dropping out or finishing with low grades (Ds and Fs). Doing this with clickers is particularly efficient in large classes. Typically, clicker software provides for a mode with which students can sign in electronically when entering the classroom. For example, Turning Point[2] (the software package used at Missouri University of Science and Technology, Missouri S&T) and other products allow for displaying a grid of numbers where every number represents a specific clicker. By pressing any key on a registered clicker, the field of the respective number will change color so that the student can identify whether or not the clicker is working properly. This procedure is helpful for establishing student confidence in the clicker hardware and software. Instructors who memorize the number-to-clicker-to-student assignments will know right away which students are missing. This might be possible (albeit unnecessary) in small classes, yet it is impractical for large class sizes. The computer system records the electronic sign-ins for analysis later, although the accuracy of this individualized count depends mainly on the students’ ethical behavior requiring that they operate only their own clicker and do not bring someone else’s to cover for absence.

While the electronic sign-in procedure may be useful during the first days of class in generating confidence in the functionality of the response devices, a different technique is more exciting to students and instructor, contributing to a relaxed and positive social classroom environment. For example, a simple demographic question like: “What is your favorite color?” with several basic choices including “None of the above” as a possible answer may surprise the audience that blue is usually favored by most. The recorded answers still allow the instructor to check the number present. Other questions such as: "How many years of high school chemistry did you study?" may be helpful for the instructor to define a level of expectation, and for the students to position themselves with respect to the rest of the class. Finally, questions that are somewhat related to the subject matter are, in general, excellent icebreakers. One of the author's favorites is:

What does the term "mole" refer to?

1. Loschmidt's number
2. A small rodent digging through our backyards
3. A TV reality show of physical and mental challenge
4. Avogadro's number
5. A small dark spot on the skin (melanocytic naevus)
6. The number 6.02214×10^{23}
7. A Mexican hot sauce (from the Aztec word "molli")

If the mind of the students is set on the topic of general chemistry, the most frequent answers will be 4 and 6, even though no wrong answer is listed here.

"Click"—I Am Prepared

Rather than reading ahead and getting informed about the subject matter that will be covered at the next class meeting, a vast majority of students, particularly in entry-level science courses, expect the instructor to recite the textbook with an emphasis on those parts that will be quizzed during the next exam. Although extensive textbook recitation might be well-liked by the students, it almost renders the instructor obsolete, because everything could readily be extracted from reading the book. On the contrary, assigned textbook reading to get students ready for class can tremendously enhance the learning experience because classroom time can more effectively be used for conceptual learning, thought-provoking discussions, and in-depth cognitive experiences.

Because students often resist or forget to read the text assigned, rigorous and frequent testing is necessary to ensure the desired effect of preparedness. For this, clicker questions are most efficient and least time-consuming, and also provide immediate feedback on the degree of preparedness. If systematically conducted at the beginning of every lecture, the assigned-reading test question may even be used as the attendance test. One simple, well-chosen, and appropriately graded question is usually sufficient to assure a minimum level of preparedness for the topics covered in class. The questions could be limited to the factual knowledge of the reading assignment, while conceptual applications and deepening of understanding become the primary goals of the subsequent class time. The degree of difficulty may vary and should increase as the semester progresses. This way, students successively learn how to extract the most from textbook reading. Let the following text, for example, be a part of a textbook reading assignment *(7):*

A **nonelectrolyte** is a substance that dissolves to form a solution that does not conduct electricity. Nonelectrolyte solutions (solutions of nonelectrolytes) do not contain ions. Aqueous solutions of acetone (**1**) and glucose (**2**) are nonelectrolyte solutions. … A **strong electrolyte** forms a solution in which the solute is present almost entirely as ions. Hydrogen chloride is a strong electrolyte, so is sodium chloride. Most soluble ionic compounds are strong electrolytes. Very few molecular compounds are strong electrolytes, HCl, HBr, and HI are three examples. A **weak electrolyte** …

A relatively simple question probing into the assigned textbook reading is whether it is possible to make a nonelectrolyte solution. Nearly everyone who has attentively read the text will remember that not only electrolyte solutions (with different amounts of ions) but also nonelectrolyte solution can be formed. Some might even remember that glucose and acetone solutions were given as examples. The following question, however, requires a higher degree of retention and challenges the reading skills of the students:

Very few molecular compounds are strong electrolytes. Among these is:

1. SF_6
2. HBr
3. C_6H_6 (benzene)
4. $CH_3–COOH$ (acetic acid)
5. $C_6H_{12}O_6$ (glucose)
6. HF

Students that have skimmed over the text may believe glucose might be the right choice because they remember that glucose is mentioned in the text (so is acetic acid as an example of a weak electrolyte), or they may find it challenging to differentiate between HBr and HF. The immediate feedback acquired from the number of correct and wrong answers may guide the instructor to either praise the students for a reading assignment well done while explaining why specific choices were given and are wrong, or to remind them to intensify their reading efforts. Thus, the question itself offers many ways to enter into a vivid discussion and learning experience based upon assigned textbook reading. If the reading is connected this closely to the subject matter, students will more likely enter into, and stay with, a routine of preparing for class and appreciate the effort.

"Click"—I Am Interested

One of the greatest challenges in teaching large-enrollment service courses, such as a general chemistry class that is not only (or not at all) attended by chemistry majors, is keeping students interested in the subject matter and preventing them from "zoning out" by catching up on homework, conversing with their neighbors, or simply falling asleep. Clickers provide the instructor with a unique opportunity to create initial interest and additional motivation by polling on common knowledge, opinions, estimates, or guesses.

Imagine a lecture in which the concept of concentration is introduced to the students as a concept that, to chemists, is often superior compared with the concept of density. What inevitably follows are the somewhat dry, yet important calculations determining and comparing numerical values of concentrations from data such as mass of solute and mass of solution or volume of solution. Then, calculations are usually reversed, and masses of solute will be calculated from given concentrations and solution volumes. To create an initial interest in such calculations, the instructor may precede this topic by inquiring of the students to guess what mass of salt (NaCl) is found in the blood stream of an average human adult. Valid choices for clicker responses might be given in orders of magnitude (e.g., 6 mg, 60 mg, 600 mg, 6 g, 60 g, 600 g, and 6 kg). It does not really matter which answer a student chooses; the participation itself is important. Relative to students' engagement without the question, more students will now be motivated to conduct a calculation from given data (e.g., atomic masses of Na and Cl, salt concentration of human blood, and blood volume of an average human adult) trying to figure out whether their guess was correct, close, or completely off. The initial interest not only motivates students to conduct the calculation, it also creates additional knowledge about the salt content of the human body.

Similarly, a relaxing break during a lecture about atomic models and the quantum world can be the following clicker poll that includes a twist:

> What is your opinion? Who of the following Nobel Laureates deserved the prize the most?
>
> 1. Albert Einstein
> 2. John Dalton
> 3. Joseph John Thompson
> 4. Ernest Rutherford
> 5. Robert Andrews Millikan
> 6. Lorenzo Romano Amadeo Carlo Avogadro
> 7. Erwin Schrödinger
> 8. Max Karl Ernst Ludwig Planck
> 9. Louis-Victor Duc deBroglie
> 10. Max Born

Again, it does not really matter which answer a student chooses. However, it is noted that answers 2 or 6 are misleading because these scientists lived long before the Nobel Prize was introduced and, therefore, never received the prize. An instructor may use this as a planned surprise or wake-up call and put the contributions of the above-mentioned individuals into a historic perspective. In addition, Albert Einstein will most likely collect many, if not most, of the votes. Asking students who voted for him to reason their choice will give the instructor the opportunity to straighten out the common misconception that Einstein was awarded the Nobel Prize for his theory of relativity.

The largest initial interest, and thus motivation for students to engage in the subject matter, is generated by polls on common misconceptions or controversial issues. However, to maximize participation for these polls, it is crucial that students trust the instructor and the clicker technology, especially if responses are supposed to be collected anonymously without creating an electronic record. The choice of "I don't want to answer" or "I don't know" is advisable for encouraging all students to respond.

"I Do" Category of Clicker Use

"Click"—I Learn

The subcategory *"I learn"* is probably the most common approach used by instructors who are lecturing with clickers. A question of this type assures that the students are able to reproduce what the instructor had just explained. Hence, it substitutes for the traditional surprise quiz and simply represents a swift test of whether students are still paying attention. For example, after introducing to the students several cations and anions, and explaining how these ions combine to form neutral salts, an instructor will normally present a few examples. A clicker question to test whether students were listening and are now able to reproduce the procedure is:

> Which of the following ionic compounds (salts) has a cation-to-anion ratio of 3:2?
>
> 1. Aluminum carbonate [forming: $Al_3(CO_3)_2$]
> 2. Calcium phosphate [forming: $Ca_3(PO_4)_2$]
> 3. Magnesium carbonate [forming: $Mg_3(CO_3)_2$]
> 4. Sodium nitrate [forming: $Na_3(NO_3)_2$]

Although this on-the-spot assessment represents a mere communication check and does not guarantee a lasting learning experience, its impact should not be underestimated. The student entries deliver the often-praised immediate and quantitative feedback indicating to students and instructor how well the message was delivered. Repeating a question or posting a similar one after additional clarification can be used for progress evaluation as well as student satisfaction.

In a workshop about the benefits of clickers *(8)*, the author conducted a test addressing the engagement of an audience that consisted of faculty, staff, and graduate students. Exactly half the audience was handed a clicker for a live test. After exemplarily introducing some very simple chemical nomenclature, an "I learn"-type question resulted in 88% correct results. Pretending to strive for improving the learning experience, the author repeated explaining the nomenclature. Right before polling another question (the question chosen was almost identical to the first), the members of the audience holding on to a clicker were asked to pass it to those that did not have one. The result was a disappointing 56% of correct answers, although the subject matter had been explained twice. Because the audience members of the second poll did not anticipate the test, their engagement level was significantly lower. The test remarkably demonstrated the well-known effect that the expectation to be quizzed will lead to improved engagement.

"Click"—I Understand

While on-the-spot assessment is important to test the alertness of students, true understanding and comprehension can only be evaluated if students are asked to transfer the acquired knowledge to new content *(9)*. Clicker questions that relate to the understanding of a topic, therefore, must be conceptual. Students who understood the concept will likely choose a correct answer, while students to whom the concept is not clear will answer randomly at best.

It is still a common misbelief that multiple-choice questions, and thus most clicker questions, are unsuitable for the evaluation of conceptual comprehension, In fact, conceptual understanding can be tested already with simple true-false problems *(10, 11)*. Let us assume an instructor has introduced (or the students have read about) concepts to predict molecular shapes and bond polarity. A simple statement such as "The molecule SF_4 is polar" with the response choices of *true* and *false* will be a mere guessing game for students who did not comprehend the principles governing the three-dimensional shape of molecules and the polarity of their bonds. It is recommended (*1,* p 31) that thought-provoking, conceptual questions should aim at about half of the class getting the correct answer from conceptual understanding. The other half will, in theory, distribute their responses randomly over all choices, so that a distribution of 75% correct and 25% incorrect answers is expected for the true-false problem above. For the SF_4 example given above, the author noticed quite frequently that students who don't fully understand the concepts of predicting molecular shapes tend to choose the incorrect answer favoring the fully symmetric tetrahedral molecular shape.

Clicker problems that lead students into choosing a wrong answer (rather than a random answer) if they don't understand the underlying concept, will possibly start vivid discussions among the students. Though it might get noisy in the classroom, these discussions should be encouraged further to promote student engagement and exploit the benefits of peer instruction *(12).* What follows is a collaborative experience during which students learn from each other. The following clicker question is another prime example for using the peer-instruction concept (*7,* p F23, Exercise B.13):

> The bromine molecule, Br_2, is known to contain two atoms of bromine. A mass spectrum of the molecular ions formed showed three Br_2^+ peaks with the mass numbers 158, 160, and 162. Which isotopes of bromine occur in nature?
>
> 1. ^{79}Br, ^{81}Br
> 2. ^{79}Br, ^{80}Br, ^{81}Br
> 3. ^{158}Br, ^{160}Br, ^{162}Br
> 4. ^{158}Br, ^{162}Br

Responses gathered from this question in an entry-level class will typically favor answers 1 and 2, while answers 3 and 4 are usually picked only to a small extent. Students who choose answer 2 missed in their conceptual understanding that the center peak (mass number of 160) originates from molecules of different bromine isotopes (i.e., ^{79}Br, ^{81}Br). With a split vote between answers 1 and 2, it is recommended that the instructor does not reveal the correct answer but rather encourages students to explain their responses to each other or dispute them in groups. In large-enrollment courses or traditional side-by-side-seating classrooms, a discussion with the immediate neighbors usually serves the same purpose.

After discussions start calming down, the question should be re-polled. Most certainly, the renewed poll will result in a higher count for the correct response. Consequently, repeating a question for which the correct answer has not yet been revealed, or posting a similar one, may be used for an assessment of the learning progress. Similarly important, a re-polled question brings great satisfaction to students who switched from a misconception to the correct understanding within only a few minutes. At this time, it might be advisable to follow up on the students' comprehension by challenging the newly gained understanding of the concept even further. For the above-mentioned problem, a follow-up question could inquire about the relative intensities expected for the peaks at 158, 160, and 162. For simplicity, an equal abundance of the two bromine isotopes may be assumed.

Instructors first exploring the utilization of clickers in their course might find it difficult to construct or design suitable problems for which a split vote is expected. Books like *Chemistry ConcepTests (13)* are a great help and valuable resource for this kind of problem, as is the ConcepTest bank *(14)* and a review of exams from previous classes. Typical mistakes or misunderstandings that occurred in exam problems are likely to occur in a similar way when polled with clicker questions. As an additional advantage, the mistakes or misunderstandings are addressed efficiently before an exam is conducted.

"Click"—I Apply

Conceptual understanding is fundamental for mastering situations in the real world; however, it might not be sufficient. After all, it is people with problem-solving skills who are highly regarded in almost all areas, not only science, technology, and engineering. In our complex society, we depend a great deal on individuals who are able to tackle and solve a wide variety of problems and challenges. In contrast, many students tend to shy away from the application of their knowledge to even simple problems and rely on a mixture of feelings and factoids. Solving challenging real-world problems, however, requires the application of conceptual knowledge in a meaningful way with reasonable approximations and justifiable interpretations.

The following clicker question, for example, could have just been a knowledge probe or guessing game:

> A chemist wishes to remove from a flask a small but highly concentrated liquid residue. A given amount of washing liquid is on hand to do the job. Which one of the following procedures is advisable?
>
> 1. Wash the flask by using the entire liquid volume in one instance.
> 2. Wash the flask with small portions until the entire liquid volume is used up.
> 3. It does not matter, because the result will be the same.

After students have mastered the concept of concentration and dilution, however, it becomes a challenge to justify a chosen response, especially because no numerical values are provided as a basis for calculations. Consequently, realistic estimates for the liquid-residue volume and its high concentration are needed. After sample calculations for both scenarios, where the number of portions in procedure 2 is again at the student's discretion, the result will likely favor response 2. However, to fully master the problem, a reasonable or, at least, plausible generalization should follow. Consequently, what is likely to have started as a guessing game is now preeminent for problem-based learning. When students are allowed, encouraged, or assigned to address the problem in groups, the situation becomes similar to industrial or business setting team efforts that are common and often necessary for dealing with a project. The instructor must carefully avoid interfering with the collaborative learning experience and should stay aside as an occasional observer or cautious thought provoker.

"I Will" Category of Clicker Use

When students come to class prepared, interested, and motivated enough to pay attention and engage into the classroom activities for the entire lecture time, a remaining challenge is to keep them further engaged after the lecture time has passed. This is usually accomplished by assigned homework problems that students are supposed to solve on their own or in groups. Another fairly simple way to keep students engaged outside the classroom involves open-ended problems discussed at the end of a lecture or tasks that appear unfinished to the students at the end of the lecture. The prospective, or promise, to be quizzed on the solution to these problems at the beginning of the next lecture will be incentive to work on the material. The instructor must not reveal the exact wording of the introductory question so that simply copying the solution from a friend (as is often done with traditionally assigned homework) is unlikely. Rather, students must engage in the subject matter to be prepared for the introductory question. The following example shows how an unfinished task may be set up. In a lecture about Lewis dot structures, a clicker question could be asked, as shown in Figure 1: What is a valid Lewis dot structure for the cyanate ion?

After students have responded with their best understanding, perhaps they will realize that there is not necessarily only one valid Lewis structure (answers 1, 4, and 5 are correct). While multiple valid Lewis structures in itself might be a surprise or novelty to the students, almost automatically a follow-up question comes to mind inquiring which is the most stable structure.

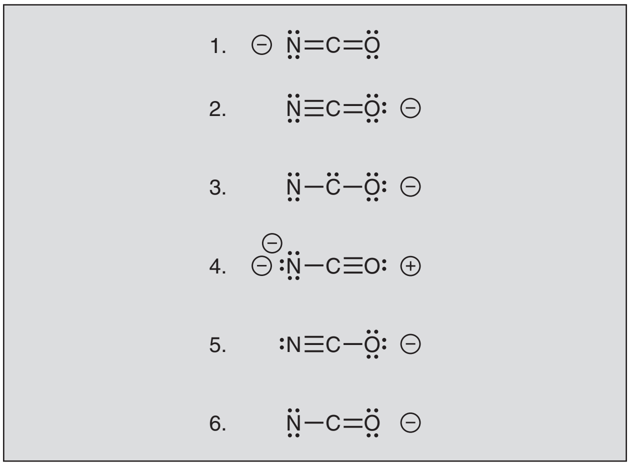

Figure 1. Image provided for the question "What is a valid Lewis dot structure for the cyanate ion?

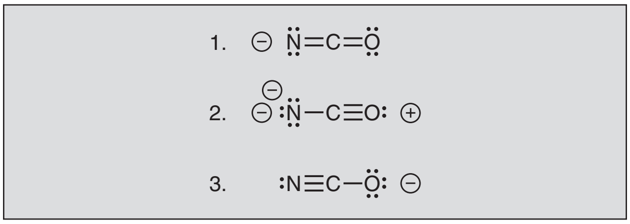

Figure 2. Image provided for the question "Which one of the following resonance structures of the cyanate ion contributes the least to the real structure?

If the assigned reading for the next lecture will be on formal charges and stability of molecules, the instructor may indicate that the first question at the beginning of the next lecture will address the stability of the cyanate ion as deduced from the different representations of valid Lewis structures. Reinforcing the content and expectations, the actual question at the next lecture could then be the one shown in Figure 2: Which one of the following resonance structures of the cyanate ion contributes the least to the real structure?

Engaging students outside of the classroom in activities that prepare them for the next lecture or recitation; helping them solve homework problems; or deepening their understanding of the topic—these are probably the greatest challenges to successfully teaching large-enrollment introductory courses. Meeting the challenges is, however, a most desirable way to enhance student progress and satisfaction. Students approaching future lectures with an attitude of "*I will be there*", "*I will be prepared*", and "*I will be interested*" have the best chances for success in class, school, and future life. The clicker technology in the classroom can efficiently help to encourage this out-of-the-classroom engagement.

Conclusion

In recent years, numerous instructors have used student response systems (clickers) to enhance teaching and learning in their classrooms. Particularly in large-enrollment introductory mathematics, science, and engineering classes, clickers make it possible to involve every student, give immediate feedback to teacher and learner, and easily assess overall learning progress. Even though one might argue that convincing data for the benefits of clickers are still missing, and educational research studies are mostly still in progress, instructors have voted with their feet by installing this technology in many classrooms and by continuing to use it. While some have been frustrated with technology failures and lack support from their institutions, most of us who have started teaching with clickers like the simplicity of the devices and the broad acceptance among students so much that it became an integral part of our everyday routine.

For many, though, integrating clickers in the classroom appears to be limited to only a few of the potential uses, such as taking attendance, probing students' comprehension of the assigned reading, or conducting pop quizzes. To better understand the full potential of clickers in the classroom, a taxonomy of tasks and activities is provided in this article that distinguishes between checking the current status of the students (the *I am* category) and probing into the learning progress of the students (the *I do* category). In summary, the categories raise the level of questioning and engagement for students from the straightforward "I am here" to the fully engaged "I apply", as outlined below.

"I Am" Category

- *"I am here"*—Taking and honoring attendance
- *"I am prepared"*—Quizzing students on assigned reading
- *"I am interested"*—Polling common knowledge to create initial interest among students

"I Do" Category

- *"I learn"*—Conducting on-the-spot assessments that provide immediate feedback to students and instructors
- *"I understand"*—Promoting critical thinking and active learning
- *"I apply"*—Incorporating problem-based learning

Finally, clickers may be used to promote learning beyond the classroom time through open-ended problems followed up at the beginning of the next lecture (the *"I will"* category). If we learn to optimize clicker utilization and use this technology in effective ways for student learning, clickers hold great promise and potential to become a lasting teaching tool.

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Notes

1. One system is CPS, a product of eInstruction Corporation, *http://www.einstruction.com/index.cfm* (accessed Jul 2008); another one is RespondCard XR, a product of TurningTechnologies, *http://www.turningtechnologies.com/interactiveaudienceresponseproducts/responsecards/responsecardxr.cfm* (accessed Jul 2008).
2. An example is vPad, a product of Turning Point Technologies, LLC, *http://www.turningtechnologies.com/interactiveaudienceresponseproducts/responsecards/responsecardvp.cfm* (accessed Jul 2008).
3. An Internet search utilizing the terms "clickers" and "high school" (accessed with *http://www.google.com* on April 22, 2008) led to a remarkable number of results in which high schools, high school teachers, and high school students present their programs or experiences with clickers.

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14. *JCE* ConcepTests for Chemistry Home Page. *http://www.jce.divched.org/JCEDLib/QBank/collection/ConcepTests/* (accessed Jul 2008). See also Kovac, J. D. *J. Chem. Educ.* **1999,** *76,* 120–124.

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