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Beyond Clickers, Next Generation Classroom Response Systems for Organic Chemistry

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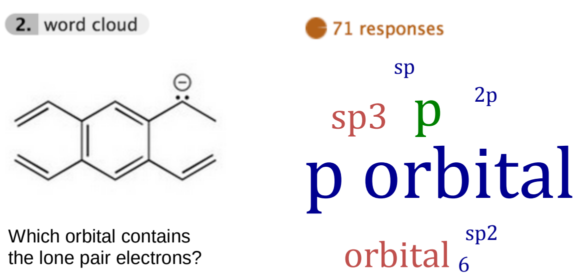
ABSTRACT

Web-based classroom response systems offer a variety of benefits versus traditional clicker technology. They are simple to use for students and faculty and offer various question types suitable for a broad spectrum of chemistry classes. They facilitate active learning pedagogies like peer instruction and successfully engage students in the learning environment. Example problems for Organic I and II are shown to highlight potential uses of one web-based system.

ABSTRACT GRAPHIC



KEYWORDS

General Public, Organic Chemistry, Curriculum, Computer-Based Learning, Cooperative Learning, Student-Centered Learning

BACKGROUND

Peer instruction using clickers is a research-based pedagogy known to improve student learning.[1] Several different types of questions are possible using traditional clicker technology including true/false, multiple-choice, and numerical. These questions can be further categorized based on the question content into ones focused on attendance, recall, algorithmic, and conceptual.[2] Concept questions in chemistry classes that promote deeper thinking and encourage student interaction have been shown to produce the largest student learning gains.[3] Organic chemists have developed several creative strategies to generate conceptual questions that can be answered with numerical clicker responses[4] including questions focused on retrosynthetic analysis[5], mechanisms with curved arrows[6], and multistep syntheses[7]. However, answering these types of questions often requires the use of numbering techniques that are cumbersome and less intuitive than traditional pencil and paper drawings.

Recent advances in classroom response systems have attempted to move beyond traditional clickers toward the use of more flexible and powerful devices like laptops, tablets[8], and smart phones[9]. These web-enabled devices offer the potential for easier student and faculty access and, most importantly, the possibility of a wider range of question and answer types. The goal for the next generation response systems is to enable students to answer conceptual questions on their devices exactly how practicing chemists would on paper or a blackboard. Thus, the questions would be open-ended and structure-based, and students would be able to draw directly on their devices to answer the questions. Several currently available systems like uRespond[10], Top Hat[11,12], and Learning Catalytics[13,14] enable these sorts of classroom interactions. In fact, uRespond was developed specifically for chemistry applications and was recently described in this journal.[15]

It has been well documented that chemistry faculty have been resistant to embrace classroom response systems, unlike their colleagues in physics.[16] One factor delaying adoption by chemistry faculty is likely the inability to ask traditional conceptual questions. The hope with this new generation of response systems is that they will find broad acceptance and adoption in chemistry classrooms, thus promoting best practice pedagogies like peer instruction to improve student learning. The goal of this article is to encourage organic chemistry faculty to consider adoption of next generation classroom response systems by providing examples from the use of Learning Catalytics in Organic Chemistry I and II classes.

INTRODUCTION TO NEXT GENERATION RESPONSE SYSTEMS

Several years of teaching using a traditional clicker system (TurningPoint) induced frustration with an inability to construct clicker questions that consistently engaged students in ways similar to problem set, quiz, and exam questions. For the past two years in Organic I and II, use of a next generation classroom response system has enabled student engagement through peer instruction with more diverse conceptual classroom problems. Questions can be easily authored by the instructor[17] or selected from a question bank containing content shared by other instructors.[18] It is simple to upload new content to the question bank; using previously uploaded problems requires searching through the material already posted by word or question-type searches.[19]

Questions are delivered directly to student devices either sequentially or all at once and can be completed during class or before class as a homework assignment. The classroom must have wireless access, and students must have a web-enabled device.[20] (Requiring the use of these devices can promote student distraction;[21] thus, instructors are encouraged to proactively address this issue with students.) Drawing with a touch screen, track pad, or mouse was equally effective, and challenges only arose when trying to draw complicated structures on screens smaller than traditional tablets. Delivery directly to each student is a major advantage that obviates the need to project or draw each question. Many question types can be graded automatically, and aggregated responses can be delivered directly to students' devices. Students always have their device (they might forget a clicker, but they never forget their phone), it is simple to use in class, and they can review all of the questions and answers outside of class. Instructors can easily check student performance in an online grade book.

Delivering questions all at once at the beginning or in the middle of class enables student groups to work through problems at their own pace. Instructors can use these response systems in ways that best suit their needs either to follow up on previously completed homework or to check comprehension of a topic just presented in class. Using the diverse question types available as a formative assessment tool, instructors can quickly gauge comprehension of interesting questions in medium to large classes and then use class time accordingly.

EXAMPLE QUESTIONS AND STUDENT ANSWERS

Instructors potentially interested in these new web-based systems are likely most curious about actual questions and student answers. What follows are examples from Learning Catalytics in Organic I and II classes at Smith College chosen to highlight different question types. Previously described applications of traditional clickers toward challenging organic chemistry problems[5-7] are possible with next generation systems. However, the goal here is to demonstrate applications focusing on graphical and structural questions that replicate the way organic chemists think about problems.

One valuable question type enables queries based on an uploaded picture. For example, a ChemDraw structure is imported and then a portion of the structure is highlighted as the correct "region" for grading purposes. Students are asked to mark the portion of the structure corresponding to the property in question. For Organic I, this tool can be used to probe student understanding of resonance structures (Figure 1). This question type also works very well for acid/base properties, such as the position of the most acidic proton and the most basic atom. The open-ended nature of these questions permits students to answer naturally, providing responses that would not normally be labeled in multiple-choice problems (e.g., mark an O when asked about the most acidic proton).

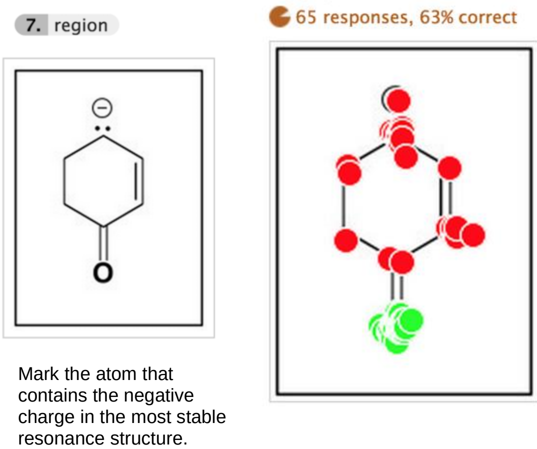


Figure 1: Resonance structure question and student answers[22]

In Organic II, these types of questions can be focused on reactions and synthesis. Figure 2 illustrates how the region question type is applied to a question about the products of an ozonolysis reaction. Retrosynthetic analysis is also possible, as demonstrated by the Mannich reaction disconnection in the tropinone problem in Figure 3.

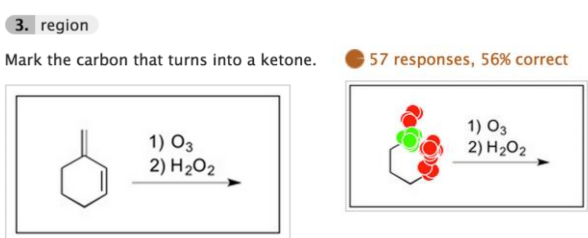


Figure 2: Reaction question and student answers

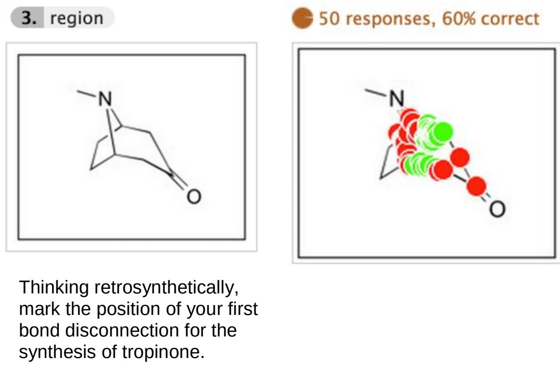


Figure 3: Retrosynthetic analysis question and student answers

An interesting drawing-based question type overlays individual answers into a single image and is not automatically graded. In Figure 4, it is easy to see that most students understand that hydroxide is not a strong enough base to deprotonate an alkyne while the other two bases will participate in the desired reaction. This question type is especially useful to quickly gauge understanding for any graphical-type problem including constructing reaction coordinate diagrams or in general chemistry when asking questions about trends using a periodic table or generating titration curves.

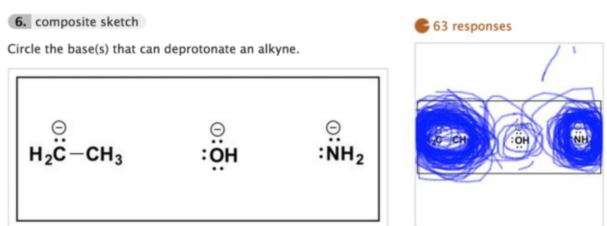


Figure 4: Drawing overlay problem and student answers

The drawing function available with next generation response systems enables students to draw molecular representations. Avoiding the image overlay described above, instructors can view individual student responses. For example, a Newman projection problem with a subset of answers is shown in Figure 5 highlighting the ease of rapidly analyzing a multitude of individual student answers.

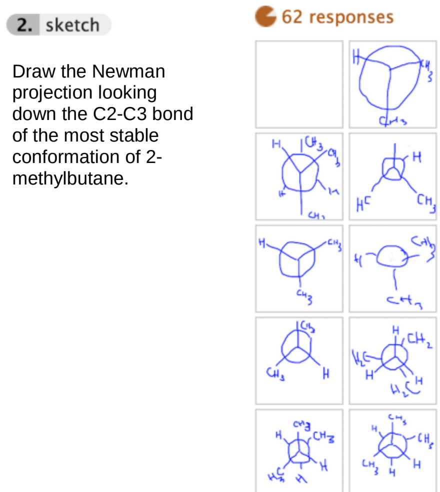


Figure 5: Drawing problem with selected student answers

Another question option that can effectively mimic how chemists think about problems is called a word cloud. These questions work well for one- or two-word answers that are displayed in varying font size based on frequency of responses. Answers to the synthesis question in Figure 6 highlight a variety of reagents promoting S_N2 or E2 reactions, the desired responses for the two- or three-step transformation of a primary bromide to an aldehyde. Interestingly, responses that might not be obvious outliers when constructing multiple choice-type questions also appear: formaldehyde, NaH, LAH, and Grignard. In fact, the unanticipated LAH, Mg, and Grignard are the second most popular answers behind the desired NaOH. Answers like these help quickly identify student misconceptions that might remain hidden with simpler multiple-choice questions.

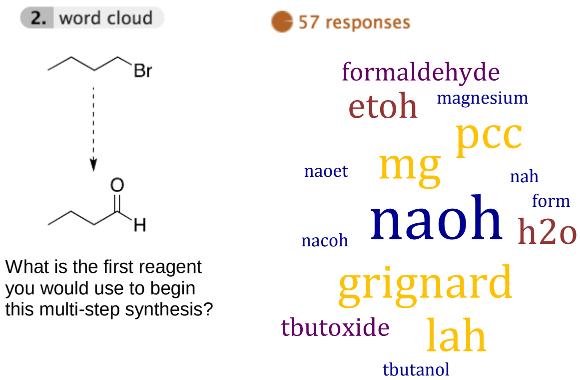


Figure 6: Word cloud problem and student answers

INSTRUCTOR AND STUDENT REFLECTIONS

When teaching introductory organic chemistry, many components are critical to successful student outcomes. My teaching philosophy and classroom strategies have evolved over fifteen years as a professor and now include custom-made videos for flipped classroom applications, mandatory group office hours to encourage student-faculty and student-student interactions, written homework due at every class meeting to promote daily engagement with course content, and the use of next generation clicker technology to facilitate peer instruction and formative assessment. Class time is used for active and vocal engagement with challenging questions where students learn from the professor and each other. Students must prepare for class and are expected to bring questions and comments for discussion. The role of the instructor is that of an adaptive expert[23] doing just in time teaching[24] for issues and misconceptions that arise from homework questions, group work in class, and answers to next generation clicker questions.

Figure 7 illustrates the number and type of questions used over both semesters of organic chemistry. The average was between five and six questions per class session with nearly half multiple-choice questions. These multiple-choice questions often focused on centering questions like comfort level on specific topics or feedback on quiz and exam perceptions. On average, there also were one word cloud, region, and numeric problem per class that focused on conceptual questions. Many-choice, sketch, composite sketch, and short answer were used infrequently. This highlights the utility of traditional multiple-choice and numerical questions supplemented by new generation word cloud and region questions.

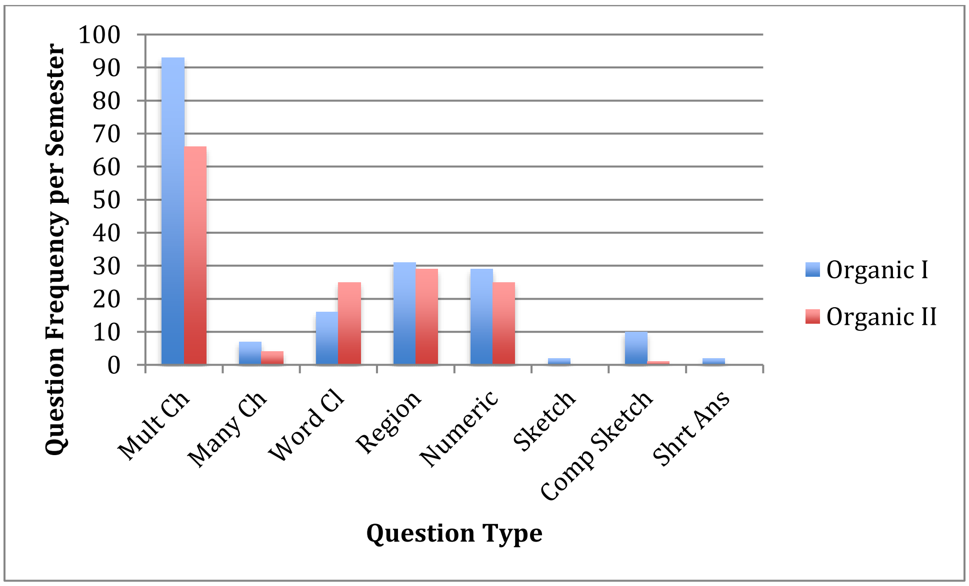


Figure 7: Question Type Summary for Organic I and II

Students have consistently provided positive feedback for this learning tool in formal and informal evaluations. They report that it improves their engagement in lecture, encourages student-student discussion, increases class participation, and helps them evaluate what they know or don't know. Specifically, they noted that it "allowed for immediate engagement and feedback which is challenging in lecture classes" and "made me engage with other students around me and helped me find a study group".

CONCLUSION

Next generation classroom response systems are a potentially valuable tool for instructors looking to build on previous use of clickers or to engage students in this manner for the first time.[25] They foster active learning through peer instruction and enable students to answer questions authentically, using structural pictures and drawings like actual chemists. It is hoped that these new technologies will prove beneficial in helping clicker-type technology "cross the chasm" and become adopted by a majority of chemistry faculty, thus enhancing the learning of a multitude of undergraduate students.

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[17] Instructors can choose from multiple-choice or numerical questions and can also use options like *sketch, composite sketch, direction, region, many-choice,* and *word cloud*, among others.
[18] As of September 2015, there were over 5,500 chemistry questions, more than 500 of which were classified as organic chemistry.
[19] Structure-based searching is not possible, and this would be a welcome addition.
[20] Smith allows students to borrow a tablet for the semester if they do not have a web enabled device. With an average class size of 72, I had only one student per semester who did not have her own device.
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[25] Instructors are encouraged to reach out to Information Technology or Educational Technology resources on their campus for potential help implementing these types of learning tools in their classes.