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Activity

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Using Errors To Teach through a Two-Staged, Structured Review: Peer-Reviewed Quizzes and "What's Wrong With Me?"

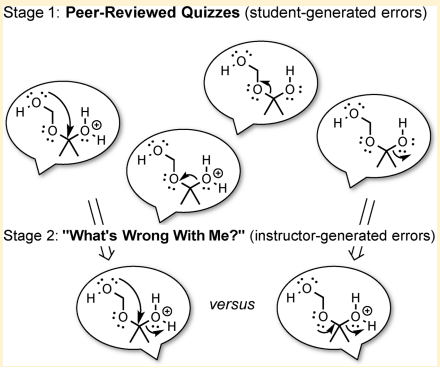
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Supporting Information

ABSTRACT: Using errors as a method of learning has been made explicit through a two-staged peer review and discussion. During organic chemistry discussion sessions, quizzes are followed by a structured peer review designed to help students identify and discuss student errors. After the face-to-face discussion, a second stage of review involves analyzing and commenting on a set of quiz solutions made available by the instructor on the course Web site. Through this "What's Wrong With Me?" exercise, students are given two solutions to each question in the quiz. One answer is completely consistent with the course, while the other contains instructor-generated errors and inconsistencies that would be marked "wrong" if graded. Students must post comments explaining solution inconsistencies to earn full credit on the quiz, and they are never told which of the two solutions is correct. This same strategy is also used for examinations and all practice problems (consisting of old exams and other problems); students never receive a single answer key for anything in the course. Course evaluations indicate strong support for peer-reviewed quizzes as generating a sense of community and facilitating learning and understanding of material. Evaluations also indicate that while frustrating at first, a majority of students find the posting of two solutions for course questions to be valuable in their learning process. This method has been by used by other faculty members, and has been implemented in general chemistry lecture and laboratory courses.



KEYWORDS: *General Public, Organic Chemistry, Collaborative/Cooperative Learning, Testing/Assessment, Learning Theories, Student-Centered Learning*

There is perhaps no more familiar saying than one version or another of "we learn from our mistakes". In education, learning from errors can be an explicit strategy for teaching, for example, when using simulations,[1] or in medical training.[2,3] There is a literature on the effects of error-making on learning[4,5] including the intriguing experimental result that taking challenging tests (i.e., ones that do not avoid errors) can promote learning.[6] A common science education strategy treats student errors as a source for a teacher's understanding of the underlying misunderstanding held by learners.[7,8] Arguably, the practice of recontextualizing errors as "misconceptions" or "alternative conceptions" takes the sting out of wrong answers by pointing to where they come from,[7] but this practice can also inadvertently validate students' mistakes under the comforting blanket of self-esteem ('there are no wrong answers') as opposed to shining a light on them as a broad instructional strategy. There appears to be a substantial gap in the literature on the structured use of errors as a learning tool for students, and we wish to report our efforts in this regard.

In some respects, learning from errors has long been an informal practice in courses. Students might compare their solutions to assigned problems with an available answer key or some source of authority (teacher, tutor, peer leader), and with one another as they work in study groups to discuss course material. While it is commonplace in introductory science courses to make answer keys to course quizzes and exams readily available to students to use in preparation for future testing in the course, misusing these resources leads to self-deception about one's learning.[9]

Resolving disagreements in a structured environment has been used in team learning and peer review exercises.[10−15] Evidence supports the idea that working together in a structured way can enhance understanding.[16−20] These strategies typically address errors generated among students as part of completing an assignment, or responding to an extemporaneous question. One of the great successes of peer-to-peer interactions is the ubiquitous report that students feel comfortable making errors in a low stakes environment without the pressure of performing in front of a traditional authority figure.[12] Electronic homework systems are built upon providing specific feedback to student errors,[21] but the act of failure is removed from the direct eyes of a typical authority, and the most common use of these systems is to allow for multiple attempts. None of these strategies are perfect: mistakes still happen, and so we raise the question, here, of how else one can use errors as a teaching tool.

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SUMMARY OF PRIOR WORK

We have described previously the formal peer-review system we implemented in the Structured Study Group (SSG) program,[12,22] in which students provide feedback on one another's work using a printed rubric. Instead of receiving their work corrected by others, students use the comments from two reviewers, plus their experience in reviewing two peers' papers, to decide if their own original work needs to be corrected, edited, or improved. These sessions, developed at the University of Michigan, take place in groups of 20 students who meet for 2 h, once a week, under the guidance of an upper level undergraduate student leader. Approximately 160 students per term use this Supplemental Instruction option as the way in which they earn Honors credit in the organic chemistry courses.

One of the assignments in which these students explicitly use errors is called "exam error check". In preparation for their SSG session, each student writes one response (a, b, or c) to an exam question of their choice, which also presumes that an instructor might have made an error in constructing a question: (a) If you judge that there is was a poorly worded or formatted question, whether you got it wrong or not, then write out why it is bad and suggest a way to rewrite it; (b) Explain why something you got wrong was actually wrong, and how you should have been looking at the information in order to get it correct the first time; or (c) If you think all of the problems are good and you got them all completely correct, then pick what you consider to be the most difficult problem and write out an explanation of the thought process used to arrive at the solution in a way that would be helpful to a peer. The assignment is then peer-reviewed according to the method described above.

Another strategy we have used in a large (400+) student setting within an even larger (1500-student) organic chemistry course is to engage the class, as a whole, in considering errors from the perspective of an instructor.[23] Using a sheet consisting of six scanned student responses assembled prior to formal grading, everyone in class thinks about what the partial credit scheme ought to be and then comes to a consensus in small group discussion. The instructor then facilitates reaching a class-wide consensus for the grading, which ends up the same or nearly the same as what the instructors decided. Finally, the members of the class are directed to use the scheme to score the six student responses, a visceral experience in understanding decisions about grading which instructors must make constantly.

REVIEW OF STUDENT-GENERATED ERRORS: PEER-REVIEWED QUIZZES

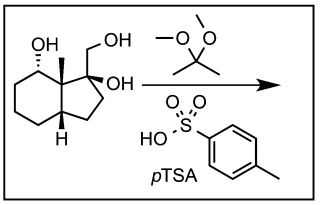
Structure of the Activity

The following activity has been carried out in mandatory SSG[22] sessions, with groups of 30−50 students under the supervision of undergraduate student instructors, in the organic chemistry program at Brandeis University.

(1) Students take an instructor-generated quiz (independently);
(2) After the quiz, students exchange papers and complete a formal peer-review sheet that focuses on anticipated problem areas with a set of simple yes/no and short answer questions to which the reviewer replies (see Figure 1 and Supporting Information);
(3) Guided by the questions on the reviewer's sheet, students work in pairs to discuss their analyses of their peers' performances;

a) Quiz Question

II.3 (14 points) Two of the alcohols below were reacted to form a stable 5-membered ring acetal. Draw the curved-arrow mechanism including all nonbonding electrons and formal charges other than zero for the reaction below. *Use H-Acid and :Base as needed.*



b) Peer Review

II.3 (14 points)

Is the acidity or basicity of the reaction accounted for in the proposed intermediates?	Yes	No
What are the charges on major Oxygen species under acidic conditions?		
What are the charges on major Oxygen species under basic conditions?		
Is the most nucleophilic alcohol reacted first?	Yes	No
Are any bimolecular substitutions shown?	Yes	No
Do kinetics or thermodynamics favor the product ring size?		

Figure 1. Example of (a) quiz question (Organic Chemistry, Spring 2012, Quiz 6, Question II.3) and accompanying (b) peer review questions. Students independently work on the quiz for 20 min, followed by formal peer review (completion of a peer review sheet for another student's quiz) for up to 10 min, then discussion with the other student, followed by discussion expansion to larger groups as needed for a total of 30 min of peer review.

(4) The discussion then expands to groups of 5−10 students with the goal of reaching consensus about the answers to the quiz problems;
(5) Students are given the opportunity to modify their quiz answers based on the peer review process.

An example of an organic chemistry quiz question and associated peer-review questions is shown in Figure 1.

REVIEW OF INSTRUCTOR-GENERATED ERRORS: "WHAT'S WRONG WITH ME?"

Structure of the Activity

Rather than using a traditional answer key, two different sets of solutions (Option 1 and Option 2) are given for all quizzes, examinations, and practice problems (consisting of old examinations and other problems) in the organic chemistry class at Brandeis University; *students never receive a single answer key in the course.*

In one of the options, the solution to a given problem is completely consistent with the information presented in the course, providing reasonable solutions and drawing reasonable conclusions; this solution would receive full credit if graded. The other option is an instructor-generated error, featuring conclusions that are inconsistent with what has been taught in the course and which would elicit point deductions if graded (i.e., a "wrong" answer). In general, the inconsistencies in the "wrong" solution are based on commonly encountered student errors. Although somewhat resistant to not having the single

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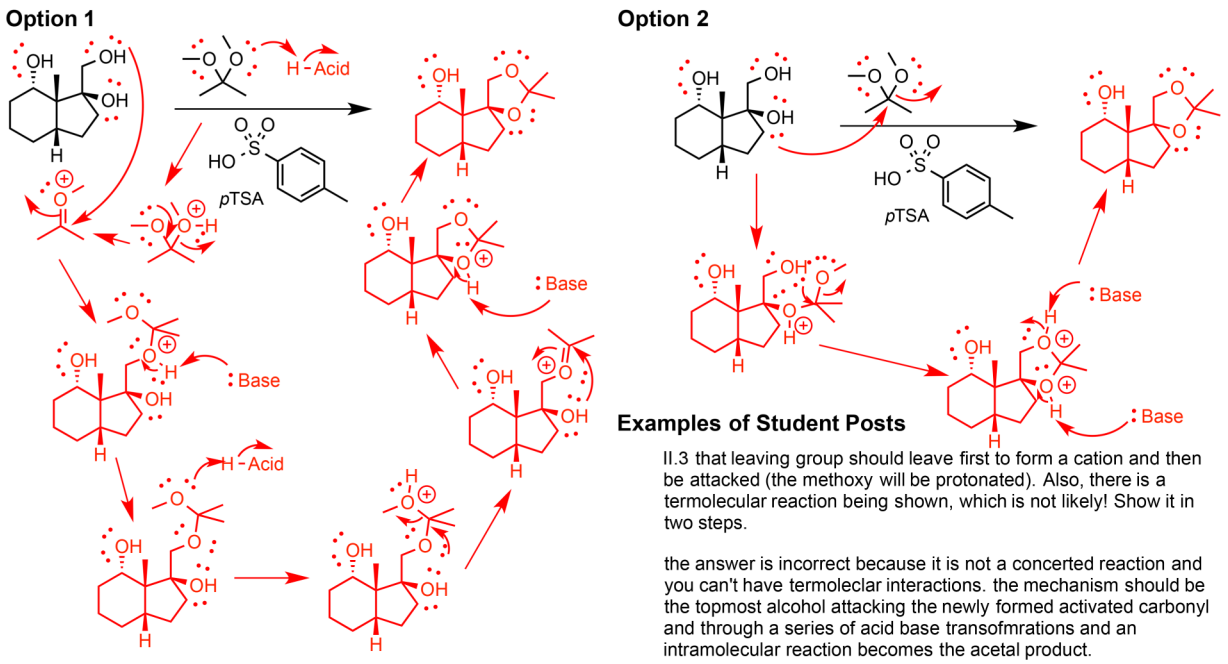


Figure 2. Options 1 and 2 solutions presented for the previously indicated Organic Chemistry Spring 2012, Quiz 6, Question II.3. One solution is consistent with the course information, and the other solution contains inconsistencies that would be marked "wrong" if graded. Examples of a few student responses to suspected inconsistencies are shown.

correct solution, students eventually expressed appreciation for the opportunity to review these "common" errors, commenting that it helps prevent repetition of the same errors in future graded materials.

An open, online discussion is used to facilitate the students' debate about the options. LATTE (Learning and Teaching Technology Environment) is the learning management system (LMS) used by the Brandeis University community. LATTE is based on the Moodle open-source platform. As part of each quiz, about 10% of the points are awarded for going to the course Web site, reviewing the two solution options for the question assigned to a student group, and posting a comment about a part of a solution they believe to be inconsistent with the course. The credit is awarded for participation, not for accuracy of the content. The fact that the students have their graded quizzes (or later, examinations) to work from is irrelevant, too, because the intent of the exercise is to focus on why the wrong answers are incorrect rather than only why the right answers are correct. We observe that the discussions rapidly converge on the options that are, in fact, the ones with the errors.

To keep the exercise manageable and meaningful for a large group of students, we divide the class of 160−240 students into 4−6 student groups, each assigned different questions to review each week. A student group could be assigned to posting comments on solutions for the recent quiz, for a recent examination, or for a part of the practice problems (consisting of old exams). Figure 2 gives examples of the two options presented for the quiz question shown in Figure 1, as well as several typical student postings. Postings remain on the course Web site for all students to then review, question, and learn from. In addition, because posts are not graded for accuracy, students need to think about their peers' comments, incorporating an additional level of reflective thought into use of the posted solutions.

Reinforcing Course Concepts

Using incorrect solutions to questions is a powerful tool to teach and reinforce many basic concepts in organic chemistry. For example, students often struggle recognizing selectivity in chemical reactions, or orders of steps in complex mechanisms. By providing two solutions to these types of problems, students are forced to consider multiple options, and explain as part of the online discussion their logical reasoning for why a given solution is inconsistent with course material. This strategy has been used to demonstrate a very large number of course topics, with a few highlighted below:

(a) Differences in leaving group ability
(b) Electrophilicity of carbonyl-based functional groups
(c) Regio- and stereoselective transformations
(d) Different types of aromatic substitution reactions
(e) Concerted vs stepwise mechanistic steps (and termolecular steps)
(f) Major species in aqueous solutions
(g) Timing of deprotonation reactions
(h) Reagents that partially reduce or oxidize functional groups
(i) Kinetic vs thermodynamic control over reactions

■ ASSESSMENT

Peer Reviewed Quizzes

Peer-reviewed quizzes were implemented during multiple semesters of the organic chemistry lecture course at Brandeis University between 2009 and 2012. A survey was given to students to assess the peer-reviewed quizzes; 93 written comments from

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students about the peer-reviewed quizzes have been generally grouped into these five categories:

1. **Understanding, Learning, and Structure.** This category includes 29 comments, which these quotes exemplify:

"Having to compare answers and justify ones own reasoning really helps me learn and grow in the course. Individual quizzes can be forgotten about easier and the theories never fully understood."

[Fall 2010]

"I truly felt that my understanding in the course is largely due to these quizzes and the peer-reviews. It allows for all the students to communicate their ideas."

[Spring 2012]

2. **Confidence and Self Assessment.** This category includes 4 comments, typified by these quotes:

"[This was] really helpful! Able to express what I'm confident I know in exchange for help from those who know my questionable areas better."

[Fall 2010]

"The quizzes are helpful in telling me how much to study."

[Spring 2011]

3. **Collaboration and Communication.** This category has 34 comments, with these representative quotes:

"I really like peer quizzes, everyone is able to contribute what they know and through the combined effort solidify what we know by explaining, and learn/understand what we previously did not through the help of our peers."

[Fall 2010]

"I found peer reviewed quizzes to be much more effective compared to independent quizzes. It promoted a sense of community and made it so people had to understand what was going on to explain it to others."

[Fall 2010]

"It would be better to have easier quizzes that are done independently. Peer-review can get confusing when people disagree."

[Spring 2012]

4. **Preparation and Copying.** This category includes 20 comments, which this quote exemplifies:

"Peer review questionnaire part is good because it gives subtle nudges. For me the worst part was when grade grubber ran around begging for answers. This is about the answer as much as the understanding."

[Fall 2010]

5. **Time Constraints.** This category has 6 comments; this quote is representative:

"I think we need a little more time for the quizzes—it's usually highly stressful to finish in time."

[Spring 2011]

Written comments indicated that students found these quizzes were valuable to their learning and understanding, increased their confidence about self-assessment, and were useful to gauge how much more to study certain material. There were a few concerns about feeling rushed to finish the quizzes in the allotted time. By far, the most common concerns expressed were that some peers were unprepared, and tended to copy answers rather than working together to reach solutions.

In addition to the free-response portion of the peer-reviewed quizzes survey, students also responded to statement items using a Lickert-scale to indicate agreement or disagreement. These data are reported in Table 1 and generally indicate strong agreement that students learned from peer-reviewed quizzes and preferred them over independent quizzes.

Table 1. Comparison of Student Responses to Peer-Reviewed Quizzes

		Averaged Results[a] by Organic Chemistry Lecture Course					
		Fall 2010, N = 139		Spring 2011, N = 115		Spring 2012, N = 177	
	Statements for Response	Avg	SD	Avg	SD	Avg	SD
1	I prefer peer-reviewed quizzes to independent quizzes.	1.4	0.6	1.3	0.6	1.4	0.7
2	I learn from other students during the peer review.	1.3	0.6	1.3	0.6	1.4	0.6
3	This method of learning has increased my:						
	a Interest in the course	1.8	0.7	1.9	0.7	2.0	0.8
	b Understanding of the material	1.5	0.7	1.5	0.6	1.6	0.7
	c Confidence in my understanding	1.7	0.7	1.7	0.7	1.8	0.8
	d Ability to communicate	1.5	0.6	1.7	0.6	1.6	0.7

[a]The scale for response ranged from 1 to 4 as follows: 1 = Strongly agree; 2 = Agree; 3 = Disagree; 4 = Strongly disagree.

What's Wrong With Me?

The *What's Wrong With Me?* resource has been implemented in organic chemistry lecture courses and laboratory courses at Brandeis University between 2009 and 2013. A survey was given to students to assess the *What's Wrong With Me?* exercise; 152 written comments from students about the *What's Wrong With Me?* exercise have been generally grouped into these three categories:

1. **Learning, Understanding, and Frustration.** This category includes 67 comments, which these quotes exemplify:

"I like this method of giving the solutions because it encourages thought instead of simple copying, especially for the practice tests"

[Fall 2010]

"It was frustrating at first not having the right answer easily accessible, but discussing which one was right and why improved understanding"

[Spring 2012]

"It is clear to see that this does encourage students to learn and analyze their mistakes."

[Summer 2012]

"Having two solutions helps in the understanding of the material. It requires the student to look at the entire answer given, rather than gloss over right or wrong examples."

[Summer 2013]

"As study tools, wrong answers don't help those of us who are already confused. As learning tools, sure, but not as review materials for exams."

[Spring 2011]

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Table 2. Comparison of Student Responses to the What's Wrong with Me Exercise

		Averaged Results[a] by Organic Chemistry Lecture Course									
		Fall 2010, N = 139		Spring 2011, N = 115		Spring 2012, N = 177		Summer 2012, N = 34		Summer 2013, N = 50	
	Statements for Response	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
1	I find the solutions helpful when studying for exams.	1.7	0.7	2.0	0.7	1.8	0.8	1.5	0.5	1.5	0.7
2	I learn from the posts from other students.	2.3	0.7	2.4	0.7	2.6	0.9	2.5	0.8	2.4	0.7
3	This method of learning has increased my:										
	a Interest in the course	2.0	0.7	2.6	2.8	2.3	0.8	2.1	0.9	2.1	0.8
	b Understanding of the material	1.8	0.6	2.0	0.6	1.9	0.8	1.6	0.5	1.5	0.6
	c Confidence in my understanding	1.9	0.7	2.2	0.6	2.1	0.9	1.7	0.6	1.6	0.7
	d Ability to communicate	2.1	0.7	2.1	0.6	2.2	0.8	2.0	0.7	2.1	0.7

[a]The scale for response ranged from 1 to 4 as follows: 1 = Strongly agree; 2 = Agree; 3 = Disagree; 4 = Strongly disagree.

2. **Posting Comments about Solutions.** This category includes 40 comments, typified by these quotes:

"The posts are helpful, but I usually don't have time to read posts from other students. The answers, both right and wrong, are helpful during studying"

[Fall 2010]

"The pressure to post means that multiple people post the same thing which does not help."

[Spring 2011]

3. **Answer Identification.** This category has 45 comments, with these representative quotes:

"It was a very nice system. However, there are many times where it would be preferable to make the answers more clearly. Though, I do see how this method would promote understanding."

[Fall 2010]

"While I appreciate that we are not given the correct answers at first, it would be helpful to have the correct answers a few days before the exam."

[Spring 2011]

Written comments generally indicated support for the *What's Wrong With Me?* activity. The majority of comments indicated that the resource helped with learning and understanding, expressing that it "encourages thought", "forced me to explain", and encourages "students to learn and analyze their mistakes". Many of the positive comments supporting the resource as a learning tool also describe it as "frustrating at first" or "annoying". It is clear students needed to adjust to the additional work required on their part to study when not given a single answer key. The most common concerns about the resource expressed preference for a "single answer key", with some suggestions to make the answers available the day before the exam. Interestingly, most of these comments also included recognition that the resource helped them learn the material and understood what the resource was designed to accomplish. An additional area of concern involved finding student posts to specific questions of interest, and a need for increased organization. It became clear that with a class of about 200 students, each posting comments each week, better organization of the posts was needed so students could utilize the posts of other students, and this will be addressed in future courses using different sections of the course Web site.

In addition to the free-response portion of the What's Wrong with Me? survey, students also responded to statement items using a Lickert-scale to indicate agreement or disagreement. These data are reported in Table 2. Students generally agreed that the resource was helpful in studying, however there was less agreement that students learned from each other's posted comments.

USE BY OTHER FACUTLY AND IN OTHER COURSES

Second Semester Organic Chemistry

Peer-reviewed quizzes and *What's Wrong With Me?* were both incorporated by another Brandeis University instructor into the second semester organic chemistry lectures during the Spring 2010 and 2011 terms, and met with generally positive student response. Typical comments from the Spring 2011 course have been included in the previous section.

General, Honors General, and Organic Chemistry Laboratory Courses

The *What's Wrong With Me?* activity has been used to promote online discussion of practice problems and exams in organic chemistry laboratory courses at Brandeis since 2009 (see Supporting Information for an example of an organic chemistry laboratory exam). The activity was also implemented in general and honors general chemistry lab courses (Spring 2011) to present solutions to weekly quizzes given during lab lecture time as well as practice problems and exams.

General Chemistry

Peer-reviewed quizzes have been incorporated into general chemistry lecture courses by two other Brandeis University instructors since the Fall 2009 semester. General chemistry instructor Claudia Novack remarks, "The peer review questions are perhaps the most important part of the quiz. I ask questions that try to give the students guidance, but the students also need to consider the questions carefully enough to appreciate the hints. I am considering abandoning the designation of "quiz" next year, and instead calling these Wednesday evening sessions "learning exercises," which will account for 10% of the total grade. I am hoping that the change in language will better reflect the intent of the exercise—not to assess or evaluate, but to learn." She has also observed, "Many students have commented that they like these exercises a lot. They appreciate the opportunity to learn and to test themselves at the same time, but without the anxiety that usually accompanies work that affects their grades. The down side is that less mature students don't catch on. They continue to rely on their friends, relieved to dodge a bullet every week, and still put off reading, doing problems, etc., until right before the exam. I can give them all the opportunity to succeed, but at some point, they

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need to take responsibility for their own contributions to the goal."

Honors General Chemistry

Peer-reviewed quizzes and the *What's Wrong With Me?* exercise have been incorporated into Brandeis honors general chemistry lecture courses Spring 2010 and 2013 consisting of enrollments of 30−40 students. Examples of honors general chemistry Quiz, Peer Review Sheet, and Solutions are available in the Supporting Information. These written comments on the formal course evaluations from honors general chemistry in Spring 2010 and 2013 represent student responses to the evaluation question, "Please identify those aspects of the course you found most useful or valuable for learning."

> *"It was also helpful that in the SSG students could work through problems together and then explain it in front of the whole class."*
>
> [Spring 2013]
>
> *"Recitation was nice because after we took our quiz, we would trade with partners, correct each others' quizzes, and then talk about them. I found this really helpful. And the worksheets we did after the quizzes were helpful too."*
>
> [Spring 2010]

Students also responded to the question "What suggestions would you make to the instructor for improving the course?" with these representative comments:

> *"[Do] more SSG review and correction."*
>
> [Spring 2013]
>
> *"The quizzes should not have a section that has to be completed online because students tend to forget about it."*
>
> [Spring 2010]

Students who referenced the peer-Reviewed Quiz or *What's Wrong With Me?* were generally positive, indicating the activities were "helpful" and "valuable". The concerns expressed by students centered around a lack of confidence in the correct solution, and some comments even requested "more" of the review exercises.

DISCUSSION AND CONCLUSIONS

Structured assignments based on errors have been generally well received by students. Evaluations reveal a preference for reviewing student-generated errors through peer-reviewed quizzes over independent quizzes, with the only significant problem being students who only seek answers rather than fully benefiting from the group learning process. The second most common concern was time pressure to complete the work during class time. To address these issues in future courses, students will complete and turn in a brief homework assignment before the quiz. The assignment will address similar content to the quiz, so students will become familiar with the material if they are not already, and the assignment will count toward the quiz grade. It is anticipated that this will increase preparation and also alleviate some of the expressed feelings of being rushed to finish.

Two interesting observations: (1) not all groups converged on the same answer—there was still large diversity in the answers presented by students on the quiz to be graded; and (2) despite the collaborative group component, grades were still not "100%", but rather in the typical 70−80% range. This is likely largely due to the level of difficulty of the quiz, written at an exam level, while the content is still newly learned and not fully studied.

Providing an additional review of instructor-generated errors through the *What's Wrong With Me?* activity elicited mixed feelings, with many students describing it as a "love-hate" relationship. Most students recognize that it forces them to learn the material more effectively; however, it also requires more effort to study than having a single answer key.

In all of these activities, we have highlighted the value of working explicitly with errors as a way to promote students' deep engagement with the subject matter. Understanding why something is wrong might be at least as valuable as understanding why something is right, and the side-by-side contrast, in principle, gives the strongest students a chance to reflect on their learning while affording the weakest students a chance to uncover the pitfalls that might have led them to the wrong solution. As an instructional strategy, we have demonstrated ways in which errors can be worked into both large and small settings, and in a few different subject areas. There is a great deal of work that could be done to further understand how working with errors might affect student learning, and we look forward to seeing how others might identify different ways to incorporate errors into teaching and learning.

ASSOCIATED CONTENT

Supporting Information

A representative example of a quiz, accompanying peer review sheet, and options 1 and 2 solutions for the *What's Wrong With Me?* exercise for the honors general chemistry course is included. An example of a quiz and exam with associated review exercises is also included for the organic chemistry course. An example of an exam for an organic chemistry lab course in included as well. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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REFERENCES

(1) Ivancic, K., IV; Hesketh, B. Learning from Errors in a Driving Simulation: Effects on Driving Skill and Self-Confidence. *Ergonomics* **2000**, *43* (12), 1966−1984.

(2) Meurier, C. E.; Vincent, C. A.; Parmar, D. G. Learning from Errors in Nursing Practice. *J. Adv. Nurs.* **1997**, *26* (1), 111−119.

(3) Fischer, M. A.; Mazor, K. M.; Baril, J.; Alper, E.; DeMarco, D.; Pugnaire, M. Learning from Mistakes. *J. Gen. Intern. Med.* **2006**, *21* (5), 419−423.

(4) Stellan, O. Learning from Performance Errors. *Psychol. Rev.* **1996**, *103* (2), 241−262.

(5) Priest, A.; Roach, P. Learning from Errors. *Cogn. Syst.* **1991**, *3* (1), 79−102.

(6) Kornell, N.; Hays, M. J.; Bjork, R. A. Unsuccessful Retrieval Attempts Enhance Subsequent Learning. *J. Exp. Psychol.* **2009**, *35* (4), 989−998.

(7) Taner, K.; Allen, D. Approaches to Biology Teaching and Learning: Understanding the Wrong Answers—Teaching toward Conceptual Change. *Cell Biol. Educ.* **2005**, *4* (2), 112−117.
(8) Hoffmann, R.; Coppola, B. P. Some Heretical Thoughts on What Our Students Are Telling Us. *J. Coll. Sci. Teach.* **1996**, *25* (6), 390−394.
(9) Chance, Z.; Norton, M. I.; Gino, F.; Ariely, D. Temporal View of the Costs and Benefits of Self-Deception. *Proc. Natl. Acad. Sci. U.S.A.* **2011**, *108* (Suppl. 3), 15655−15659.
(10) Gosser, D. K.; Roth, V. J. The Workshop Chemistry Project: Peer-Led Team-Learning. *J. Chem. Educ.* **1998**, *75* (2), 185−187.
(11) Gosser, D. K.; Cracolice, M. S.; Kampmeier, J. A.; Roth, V.; Strozak, V. S.; Varma−Nelson, P. *Peer-Led Team Learning: A Guidebook*; Prentice−Hall: Upper Saddle River, NJ, 2001.
(12) Varma-Nelson, P.; Coppola, B. P. Team Learning. In *Chemist's Guide to Effective Teaching*; Pienta, N., Cooper, M. M., Greenbowe, T., Eds.; Pearson: Saddle River, NJ, 2005; pp 155−169.
(13) Gosser, D. K., Jr.; Kampmeier, J. A.; Varma-Nelson, P. Peer-Led Team Learning: 2008 James Flack Norris Award Address. *J. Chem. Educ.* **2010**, *87* (4), 374−380.
(14) The Center for Peer-led Team Learning. http://www.pltl.org/ (accessed Feb 2014).
(15) The Center for Authentic Science Practice in Education, CASPiE. http://www.purdue.edu/discoverypark/caspie/ (accessed Feb 2014).
(16) Smith, M. K.; Wood, W. B.; Adams, W. K.; Wieman, C.; Knight, J. K.; Guild, N.; Su, T. T. Why Peer Discussion Improves Student Performance on In-Class Concept Questions. *Science* **2009**, *323* (5910), 122−124.
(17) Fagen, A. P.; Crouch, C. H.; Mazure, E. Peer Instruction: Results from a Range of Classrooms. *Phys. Teach.* **2002**, *40* (4), 206−209.
(18) Lasry, N.; Mazur, E.; Watkins, J. Peer Instruction: From Harvard to Community Colleges. *Am. J. Phys.* **2008**, *76* (11), 1066−1069.
(19) Crouch, C. H.; Mazur, E. Peer Instruction: Ten Years of Experience and Results. *Am. J. Phys.* **2001**, *69* (9), 970−977.
(20) Mazur, E. Farewell, Lecture? *Science* **2009**, *323* (5910), 50−51.
(21) Santosh, A. M.; Koedinger, K. R. Fostering the Intelligent Novice: Learning From Errors With Metacognitive Tutoring. *Educ. Psychol.* **2005**, *40* (4), 257−265.
(22) Coppola, B. P.; Daniels, D. S.; Pontrello, J. K. Using Structured Study Groups to Create Chemistry Honors Sections. In *Student Assisted Teaching and Learning*; Miller, J., Groccia, J. E., DiBiasio, D., Eds.; Anker: New York, 2001; pp 116−122.
(23) Coppola, B. P. Structure and Reactivity at the University of Michigan. In *Assessment in the Disciplines (Vol. 5): Assessment in Chemistry*; Ryan, J., Clark, T., Collier, A., Eds.; Association for Institutional Research: Tallahassee, FL, 2010; pp 175−199.