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Creative Exercises in General Chemistry: A Student-Centered Assessment

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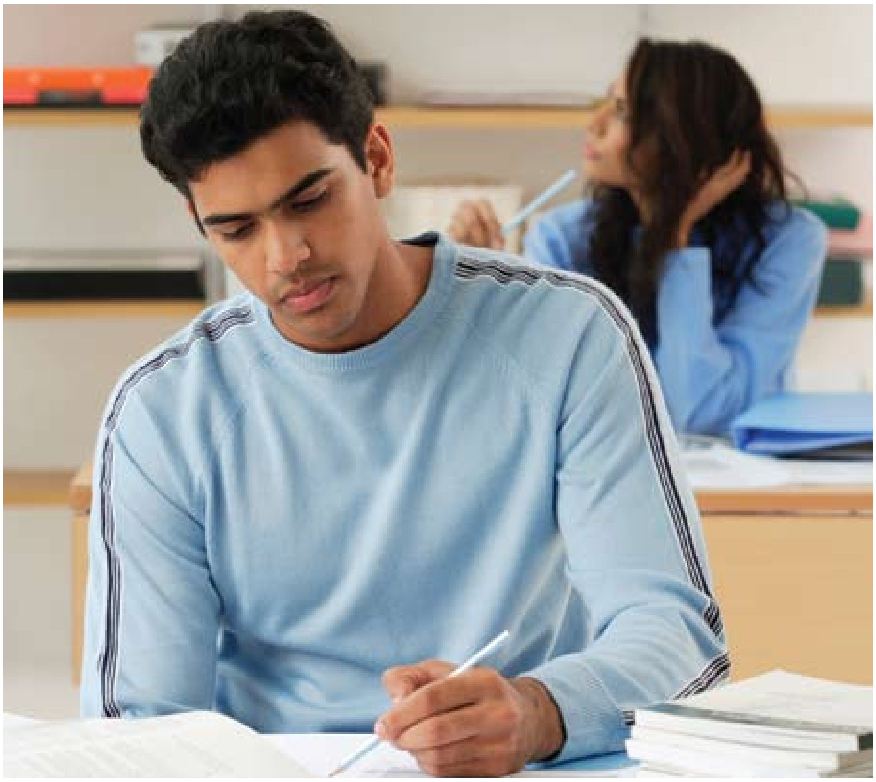
Creative exercises (CEs) are a form of assessment in which students are given a prompt and asked to write down as many distinct, correct, and relevant facts about the prompt as they can. Students receive credit for each fact that they include that is related to the prompt and distinct from the other facts they list. With CEs, students have an opportunity to demonstrate their knowledge and the opportunity to select the information that they believe is related to the prompt. In addition, CEs encourage students to connect concepts because any relevant information presented can assist them in completing the CEs. This paper describes the use of CEs in a college-level chemistry class, including student answers to the CEs and a survey of students' impression of CEs.



Traditionally, in freshman college-level science courses, students are given assessments that include multiple-choice questions or short answers with only one correct answer (closed-ended questions). In traditional assessment, the instructors select the information that is required for students to know and then verify that students know it. The intent of creative exercises (CEs) is to change the philosophy on how student knowledge is assessed. CEs, first proposed by Trigwell and Sleet (1990), are a form of assessment in which students are given one statement, or prompt, and asked to write down as many distinct, correct, and relevant facts about the prompt as they can. Students then receive credit for each fact that they include that is related to the prompt and distinct from the other facts they list. With CEs, students have an opportunity to demonstrate their knowledge (Anderson 1998). In addition, CEs encourage students to connect concepts because any relevant information presented can assist them in completing the CEs. This paper describes the use of CEs in a college-level chemistry class, though we believe they could easily be incorporated into a physics or biology class.

Creative exercises as a student-centered assessment

In student-centered teaching, students take an active role in the learning process through negotiating meaning and in developing a conceptual understanding (Tien, Roth, and Kampmeier 2002). Likewise, we have termed CEs a student-centered assessment because students take an active role in determining and presenting the knowledge to be assessed. Traditional assessments, such as multiple choice or short answer, are teacher-centered assessments in which the teacher determines entirely what is to be measured for a successful performance on an exam. This has the potential to provide only a partial picture of a student's knowledge in a course. For example, a student may know relevant information that was not included on the exam. Additionally, there is a tendency with traditional assessment questions to focus exclusively on material recently presented, which does not value information previously presented in the course. We hypothesize that this may be a cause of poor learning retention. In contrast, CEs give students an opportunity to both present their knowledge as they determine it and reward students for the retention of previously presented concepts.

Other assessments have been developed that allow students to determine what information to present, such as open-ended essay questions. We believe that CEs are unique to these assessment techniques. Open-ended essay questions may not explicitly require students to relate recently presented topics to previous topics, for example. Essay questions may also use complex grading schemes to evaluate the student's logic and organization in their argument. Although these are certainly desirable traits to measure, their incorporation makes grading difficult, especially as class sizes grow. Additionally, essay questions have a tendency to focus on one particular science concept in-depth. On occasion, a carefully designed essay question may encompass a variety of concepts within a course, but such questions are challenging to design and often cannot be administered during class because of concerns of class time. The latter is important in cases in which a faculty member wishes to evaluate student knowledge without the student accessing outside resources as well as to reduce the opportunity for cheating. In contrast, CEs are relatively straightforward to design and grade and can be completed by the student within a few minutes, allowing in-class administration.

FIGURE 1

Creative exercise examples.

Write down as many correct, distinct, and relevant facts you can about:

7.5 g of $CaBr_2$ is dissolved in a 1.50 L solution of excess Li_2CO_3 in the reaction

$$CaBr_2\,(aq) + Li_2CO_3\,(aq) \rightarrow CaCO_3 + LiBr$$

You'll receive 2 points for each statement. Seven statements will get you full credit for the problem.

For problems that provide a mass, solving for the molecular mass and the number of moles for a compound, count as only one distinct fact.

The guideline for distinct also requires a unique calculation from your other calculations or a statement that adds knowledge independent of your previous statements.

Use of creative exercises in the classroom

To design a CE, the instructor need only to come up with a statement or description of some facet of the class that is to be assessed and the maximum number of statements the instructor expects students to be able to complete. An example of a CE is shown in Figure 1.

TABLE 1

Creative exercises used for homework assignments.

Assign	Prompt	Maximum statements	Topic
1	An atom of Germanium-72	5	Structure of atom
2	7.5 g of $CaBr_2$ is dissolved in a 1.50 L solution of excess Li_2CO_3 in the reaction: $CaBr_2\,(aq) + Li_2CO_3\,(aq) \rightarrow CaCO_3 + LiBr$	7	Reactions in solution
3	In the reaction below, 23.0 g of $FeCl_2$ undergoes the reaction in 5.15 L of water initially at 25.0°C (assume 1.0 g / ml). $FeCl_2(s) \rightarrow Fe^{2+}(aq) + 2\,Cl^{-}(aq)$ $H_f(FeCl_2) = -341.8$ kJ/mol $H_f(Fe^{2+}) = -87.9$ kJ/mol $H_f(Cl^{-}) = -167.46$ kJ/mol	7	Thermodynamics
4	$H_2(g) + Cl_2(g) \rightarrow 2\,HCl(g)$	5	Covalent bonding and electronegativity
5	The ion SF_5^{-}	5	Molecular shapes and polarity

We have developed and used five CEs as homework assignments and four CEs on in-class examinations throughout a semester-long course. Students were given the first homework CE without any prior training because we wanted to ensure that this assessment could be implemented with minimal intervention. We introduced CEs as a homework assignment that was relatively low risk for students' grades. This prepared the students for the later inclusion of CEs within their in-class tests. After the first homework CE, a rubric was posted to inform students of the variety of facts that would be counted. The five homework CEs are presented in Table 1. Table 1 indicates the maximum number of facts students received credit for, which limits the points possible for the assignment. Instructors can manipulate the maximum number of statements needed for full credit to make the problem more difficult (more statements) or easier (fewer statements). In our experience, students tended to go to outside sources (typically the internet) for information, so we added the following to the directions: "Each statement you use should refer to material that has been presented in this course. You can use outside information (such as other reference material) but that will only count as one statement, regardless of how much information is presented from other sources." This instruction could be removed if the instructor wishes to encourage students to research outside information.

One of the in-class CEs was embedded in each of the four in-class midterm conventional exams. The four in-class CEs are presented in Table 2. Outside information was not a concern with these, as the exams were closed book and administered during class time. As before, we set a maximum number of statements required for complete credit for the CE. To encourage students to use as many facts as possible, we also included room for extra credit for additional statements. So on the first assignment, in which the maximum statement is 5 + 3, there are five statements required for complete credit, and students received extra credit for up to three statements beyond the five. In this way, students were not penalized if they could only reach the number of statements for complete credit. Embedding the CEs within a conventional multiple-choice exam provided a beneficial combination. We could

FIGURE 2

Rubric for the example creative exercise shown in Figure 1.

- Molecular mass of $CaBr_2$ is 199.88 g/mol, 0.038 moles of $CaBr_2$
- Moles of any other species (0.038 moles of $CaCO_3$, 0.076 moles of LiBr)
- Balance the reaction
- Identify product LiBr as aqueous
- Identify product $CaCO_3$ as solid (or identify the reaction as a precipitation reaction)
- Molarity of LiBr is 0.050 M, of $CaBr_2$ is 0.025 M
- Grams of $CaCO_3$ is 3.8 g (or grams of LiBr that could be recovered)
- Identify balanced equation as molecular equation
- Total ionic equation
- Net ionic equation
- Spectator ions identified
- Identify CO_3^{2-} ion as carbonate (or any polyatomic ion)
- Ca^{2+} is a cation or Br^- is an anion, $CaBr_2$ is an ionic compound
- $CaBr_2$ identified as the limiting reagent (but no credit for saying "limiting reagent problem")
- Percent composition of Ca in $CaBr_2$ is 20.0%, percent composition of Br in $CaBr_2$ is 80.0%
- Atomic number of Ca is 20 (or number of any subatomic particles for any atom listed)
- Can get credit for one fact outside of what is presented in the course

TABLE 2

Creative exercises used for in-class assignments.

Assign	Prompt	Maximum statements	Topic
1	33.5 g of $CaCl_2$	5 + 3	Mass to mole
2	Reacting 223 mL of 0.15 M of HCl with excess Magnesium $Mg(s) + 2\ HCl(aq) \rightarrow H_2(g) + MgCl_2(aq)$ This reaction occurs at 1.25 atmospheres (atm) and 24°C.	7 + 2	Gas laws
3	In the reaction below, 28 g of Cl_2 react with excess BF_3. $2\ BF_3(g) + 3\ Cl_2(g) \rightarrow 2\ BCl_3(g) + 3\ F_2(g)\ \ \Delta H = 1466.4$ kJ/mol	5 + 3	Thermodynamics
4	COH_2 where C is the central atom Electronegativity values: C = 2.5, H = 2.1 and O = 3.5	5 + 2	Molecular shapes and polarity

use the multiple-choice questions to measure whether students met specific course objectives (Weld 2002), and the CEs allowed the students to determine and present the concepts that they had acquired.

Grading of creative exercises

Prior to grading CEs, a panel composed of the course instructor, another instructor who has taught the course, and a senior-level student in a teacher preparation track brainstormed possible statements on the basis of information presented in the course to generate a grading rubric. The grading rubric was not shared with students until after the assignment. Typical grading rubrics included approximately 15 statements that students could have received credit for. In addition, by some statements in the rubric, there are lists of additional information that was considered redundant or not distinct. For example, if a student correctly solved for the mass percent of calcium in $CaBr_2$, he or she would not receive additional credit for solving for the mass percent of bromine or for solving the percent composition of other compounds in the reaction. Also, students would get credit if they solved for the moles of one product in a chemical reaction, but if they solved for the moles of other compounds, they received no additional credit because the calculations are similar. Students were informed ahead of time that repeating similar calculations would not count as distinct facts (see example previously provided). Figure 2 shows the rubric for the example CE in Figure 1.

In this rubric, each bullet point lists what was considered a correct statement, and each separate bullet point lists a statement that is considered distinct from the other bullet points. The list of possible responses is not exhaustive, because CEs are explicitly an open-ended assessment in which there are a large set of possible correct answers. In our experience, however, the rubrics created describe all of the student responses used by the majority of our students. In instances in which students list a statement that is not listed in the rubric, a decision on the statement is made on a case-by-case basis and incorporated into the rubric. After the assignment is graded, the rubric is posted for the students in order to reveal the variety of possible statements that received credit.

Examples of student responses

We have used CEs in two first-semester general chemistry classes at a medium-sized, public, four-year university in the southeast. One class held approximately 70 students, and the other class held approximately 50 students. The demographics of the classes were 66% female and 70% white, with Asian (9%) and black (9%) as the most represented minorities.

Figure 3 shows student responses to the homework assignment #3 (see Table 1). Each student response is reported in verbatim from the students' answer sheets, except that line numbers are added to assist with the discussion that follows. Each student consented to the use of his or her response without identifying information.

This CE required seven facts for full credit, and student 1 listed nine facts. The student received credit for lines 1 through 5 as each fact is distinct, relevant, and correct. Lines 6 and 7 were considered similar calculations so the student received credit for just one of these two facts. Line 8 was also considered valid, so the student received full credit for seven facts. Line 9 was correct, but because the student reached the maximum seven facts, it did not need to be graded.

For student 2 (see Figure 3), credit was not received for lines 1, 2, and 4, as these are incorrect facts. For lines 1 and 2, no precipitate is formed in this reaction, and for line 4 the incorrect number of moles is indicated. Line 5, using the volume of solution

FIGURE 3

Responses of students 1 and 2 to the homework assignment #3 in Table 1.

Line	Student 1
1	The reaction is exothermic
2	The total heat of reaction is -81.02 kJ
3	5150 ml × 1 g / ml = 5150 g of H_2O
4	23 g $FeCl_2$ × -81.02 kJ/126.75 g = -14.70 kJ needed to react 23 g $FeCl_2$
5	23 g $FeCl_2$ * 1 mol / 126.75 g = 0.1815 mol $FeCl_2$
6	0.1815 mol $FeCl_2$ × 2 mol Cl^- / 1 mol $FeCl_2$ = 0.363 mol Cl^-
7	0.1815 mol $FeCl_2$ × 1 mol Fe^{2+} / 1 mol $FeCl_2$ = 0.1815 mol Fe^{2+}
8	$Fe^{2+} + 2\ Cl^- \rightarrow FeCl_2 \rightarrow H_{rxn}$ = 81.02 kJ
9	The opposite reaction is endothermic

Line	Student 2
1	$FeCl_2$ (*s*) → Fe^{2+} (*aq*) + 2 Cl^- (*aq*) is net Ionic
2	Precipitation reaction
3	Cl^- is soluble
4	0.1563 mol $FeCl_2$
5	147.15 × 0.0821 × 298.15 / 5.15 = pressure is 699.41
6	Exothermic reaction b/c the #'s are negative
7	Releases heat
8	ΔH_f ($FeCl_2$) = -341.8 kJ/mol
9	0.1563 mol $FeCl_2$ × (-341.8 kJ / 1 mol) = -53.42 kJ/mol

in the ideal gas law formula, was also incorrect and revealed how students can improperly connect content in a course. The student received credit for line 3 because Cl^- is the reason that the compound is soluble and line 6 because the reaction is exothermic. Line 7 was considered a duplicate of line 6. Line 8 is stated in the problem so no credit was awarded. In line 9, the student solved for the heat of formation for the sample of $FeCl_2$, which is not relevant to the chemical reaction written and also incorrect because of the resulting units. Ultimately this student received credit for two facts out of the seven maximum: lines 3 and 6. Students are encouraged to write more than the maximum number of facts if they are concerned about a pair of facts not being distinct from each other, as student 2 wrote nine facts, though only seven were needed for full credit. Students are not penalized for any incorrect facts written. In some rare circumstances, a student would put "It is endothermic" followed by "It is exothermic"; in these cases, no points were awarded as the two facts directly contradict each other.

Faculty considering CEs may be concerned about the amount of effort and time involved in grading an open-ended assessment, particularly with large classes. In our experience, it takes about one hour to grade a CE for a class of 70 students. We did note that CEs that do not have values provided, such as homework 4 and 5 and in-class 4, were notably easier to grade for two reasons. First, without values such as mass, there were fewer items that students could incorporate. Second, when there were values present, if a student made a mistake early in the calculations, we did follow through with the remaining calculations to give students credit for following a correct procedure or algorithm even if his or her earlier calculation was incorrect. Even so, the grading of CEs was not overly difficult or time-consuming, and the use of CEs rewarded students' efforts to relate concepts and informed us of students' misconceptions as discussed in the next section.

Faculty at another institution using CEs in their classes concurred: "In our experience, the information and insights that we get back from CEs far outweigh the time that it takes to develop the CE and to comment on student responses" (G.H. Webster, personal communication, April 2009).

FIGURE 4

Questions in the online survey.

These questions refer to the assignments where you are asked to "write down as many distinct, correct, and relevant facts about …" We'll refer to these questions as "Creative Exercises" for the purpose of this survey.

1. Do you think doing Creative Exercises as take-home assignments helped you learn the material?
2. Do you think your score on the Creative Exercise take-home assignments reflects the effort you put into the assignment?
3. Do you think the score for the Creative Exercise questions asked at the end of each test is an accurate measure of your knowledge on the topic selected?
4. The Creative Exercise questions on the tests essentially had an option to earn extra credit for providing more facts than required.

   Did you attempt to earn extra credit on these questions?

   If not, what was the primary reason for not attempting to earn the extra credit?
5. Given a choice, would you want Creative Exercises as part of the assignments and test questions in future chemistry courses? You may also want to include any suggested revisions to the Creative Exercises here.

Results from creative exercises

One of the principle benefits from using CEs is that graders become acutely aware of misconceptions and inappropriate conceptual connections students may make. For example, when attempting to write the ionic reaction for the CE in Figure 1, many students wrote Li_2^{2+}, treating lithium as a polyatomic ion. For another example, on assignment 3 (Table 1), students labeled the $FeCl_2$ reaction as exothermic because the heat of formation for $FeCl_2$ is negative, rather than solving for the ΔH of the reaction. These kinds of misconceptions can then be discussed in class to improve student learning, and may be missed if an instructor relies on multiple-choice tests alone.

As mentioned, our intent with CEs was to deliberately reward students for relating concepts in the course, and this was observed in student responses. For example, in the fourth homework, CE students were just given the reaction $H_2 + Cl_2 \rightarrow 2\,HCl$ right after covalent bonding and bond energies were introduced. It was our expectation that students would focus on differences in electronegativity, the comparison of bond lengths between the three molecules, and estimate the change in enthalpy using bond energies. Although many students did this, we also observed a number of students pulling in concepts that had previously been tested. For example, of the 76 students who completed this assignment, 40 of the students indicated that HCl was an acid, 31 students determined the electron configuration of one of the atoms, and 4 students estimated the change in enthalpy using heats of formation. Each of these concepts was presented and assessed well prior to this assignment. This was not an isolated incident, and many students continued to practice naming, bonding type, mass percent of compounds, and mole calculations throughout the semester even during later topics that did not explicitly invoke these concepts. We believe that seeing the interconnectedness of the different chemistry topics throughout the course assists students in developing a deeper understanding of how concepts relate, rather than seeing topics as discrete, unrelated facts. One interesting topic for future study would be to incorporate CEs into a follow-up course, such as second-semester general chemistry or a related science course, and investigate whether students continue to use the concepts presented in first-semester general chemistry.

To assess student opinions of CEs, we used an anonymous online survey. Only students enrolled in one of the courses could take the survey, and each student could only take the survey once. The survey asked a series of open-ended questions about CEs, with 53 students completing the survey (see Figure 4 for the questions included in the survey). The first question inquired if students thought the take-home CEs helped them learn the material in the course. Of the 53 responses, 44 were positive, and one of the most common responses was that the CEs required students to think outside of the box or review their past notes for possible connections. Among the negative responses, one student felt that there should be a required number of math problems, and another student felt that although CEs did not help him to learn, the CEs did indicate which areas the student was not clear on. When asked if the score on the take-home CEs reflected their effort, 40 of the 53 students indicated *yes*, with a common comment being that it took one or two assignments to get the hang of it.

Also on the survey, students were asked if the in-class CE scores were an accurate measure of their chemistry knowledge. For this question, 33 of the 53 responses were positive. Two reasons were commonly cited for why the CEs were not an accurate measure: six students indicated that their mind would go blank or freeze up when they got to this question on the exam, and three students felt they did not have enough time to answer the CE. To investigate further, we correlated students' performance on the in-class CEs with the final exam scores for the 65 students in this study who completed the course (of the 100 who consented to the study). The final exam was the American Chemical Society (ACS) 2002 General Chemistry First Term Exam (Examinations Institute of the American Chemical Society Division of Education 2002). The four in-class CEs had correlations ranging from 0.53 to 0.63 with the ACS Final Exam. By comparison, the conventional multiple-choice part of the exam had correlations ranging from 0.63 to 0.76 with the same ACS final exam. It is understandable that the one-question CE would have a lower correlation with the ACS than the series of questions from the multiple-choice exam. However, the range of 0.53 to 0.63 indicates a moderate to strong correlation of the in-class CEs with the ACS exam, and although the sample size is too small to be conclusive, it does show preliminary evidence that the in-class CEs are a valid measure of chemistry knowledge (Cohen 1988). As a result, we intend to direct future studies to investigate the validity and reliability of CEs.

In conclusion, we have found CEs in the general chemistry curriculum to be a practical and useful tool for assessment of students' knowledge and for providing information regarding students' misconceptions. Additionally, we believe that the use of CEs encourage students to relate concepts within a course, though this will require further study. There is some preliminary evidence that CEs are a valid measure of chemistry knowledge when correlated with a widely used measure of chemistry knowledge, the ACS exam. We also found that students, overall, responded positively to the CEs. The final question on the survey asked, if given the choice, would students like to see CEs in future chemistry courses. Fifty of the 53 students said *yes*, with one comment in particular standing out: "Yes, because the 'creative exercises' are so much better than the standard-type questions that the book gives. Plus it's like it's your time to shine because you can show what you have learned." ■

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